US009110512B2

(12) **United States Patent**
Exner

(10) **Patent No.: US 9,110,512 B2**
(45) **Date of Patent: Aug. 18, 2015**

(54) **INTERACTIVE INPUT SYSTEM HAVING A 3D INPUT SPACE**

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(73) Assignee: **SMART Technologies ULC**, Calgary (CA)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 631 days.

(21) Appl. No.: **13/436,603**

(22) Filed: **Mar. 30, 2012**

(65) **Prior Publication Data**

US 2012/0249762 A1 Oct. 4, 2012

Related U.S. Application Data

(60) Provisional application No. 61/470,409, filed on Mar. 31, 2011.

(51) **Int. Cl.**

H04N 7/18	(2006.01)
G06F 3/01	(2006.01)
G06F 3/03	(2006.01)

(52) **U.S. Cl.**
CPC ***G06F 3/017*** (2013.01); ***G06F 3/0304*** (2013.01)

(58) **Field of Classification Search**
CPC ... G06K 9/00; G06K 9/00671; G06K 9/3216; G06K 9/3241; H04N 1/00326; H04N 1/00411; G06F 3/04815; G06T 19/006; G06T 2207/30204
USPC 348/61
See application file for complete search history.

(56) **References Cited**

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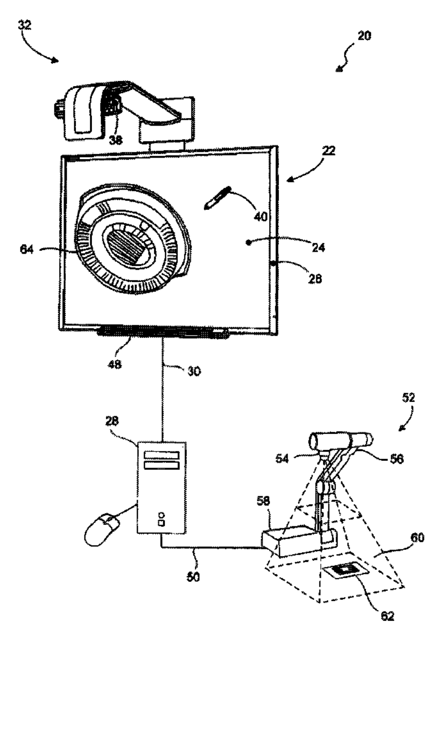
Primary Examiner — Mehrdad Dastouri
Assistant Examiner — Obafemi Sosanya
(74) *Attorney, Agent, or Firm* — Katten Muchin Rosenman LLP

(57) **ABSTRACT**

An interactive input system comprises computing structure; and an input device detecting at least one electronic device displaying a recognizable pattern within a three-dimensional (3D) input space and providing output to the computing structure. The computing structure processes the output of the input device to recognize the pattern displayed by the at least one electronic device in the 3D input space; detect the state of the at least one electronic device; and modify image data by applying a transition to digital content associated with the displayed pattern based on the detected state of the at least one electronic device.

20 Claims, 22 Drawing Sheets



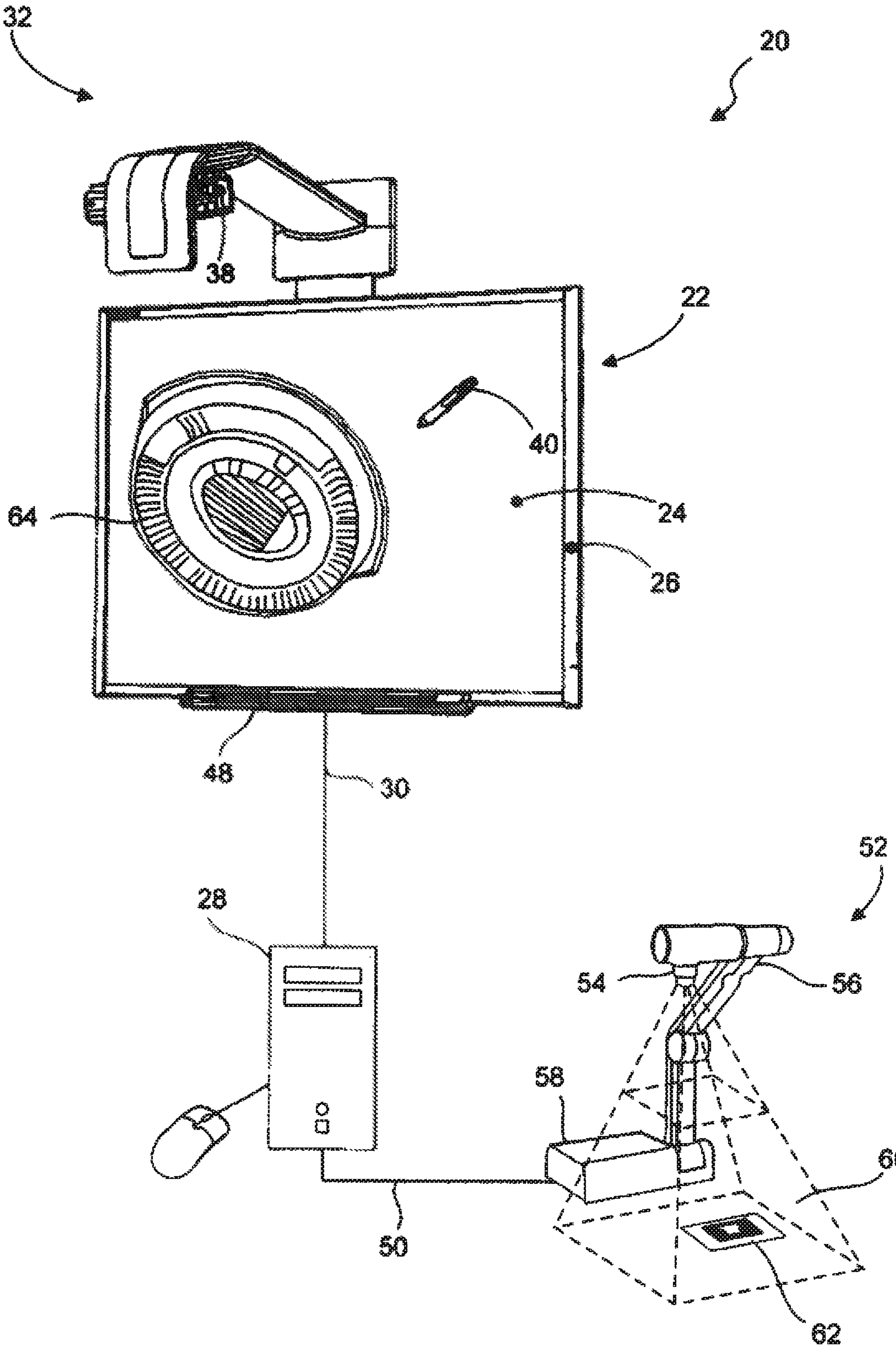


FIG. 1A

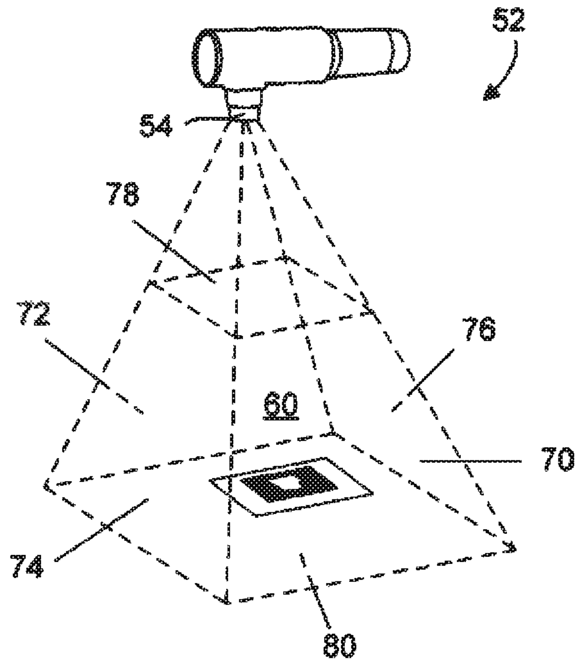


FIG. 1B

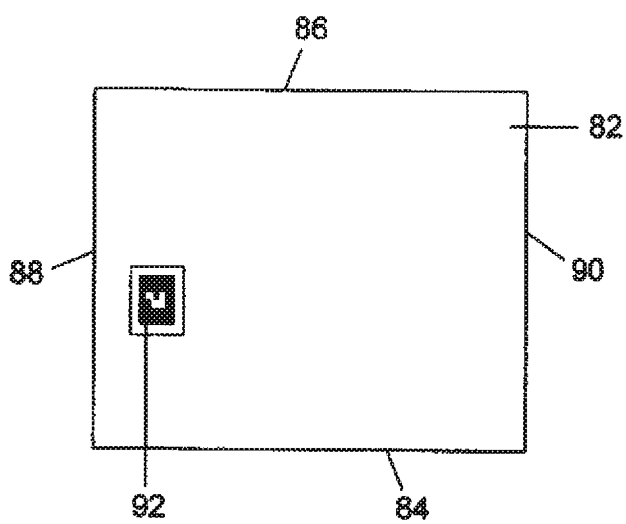


FIG. 1C

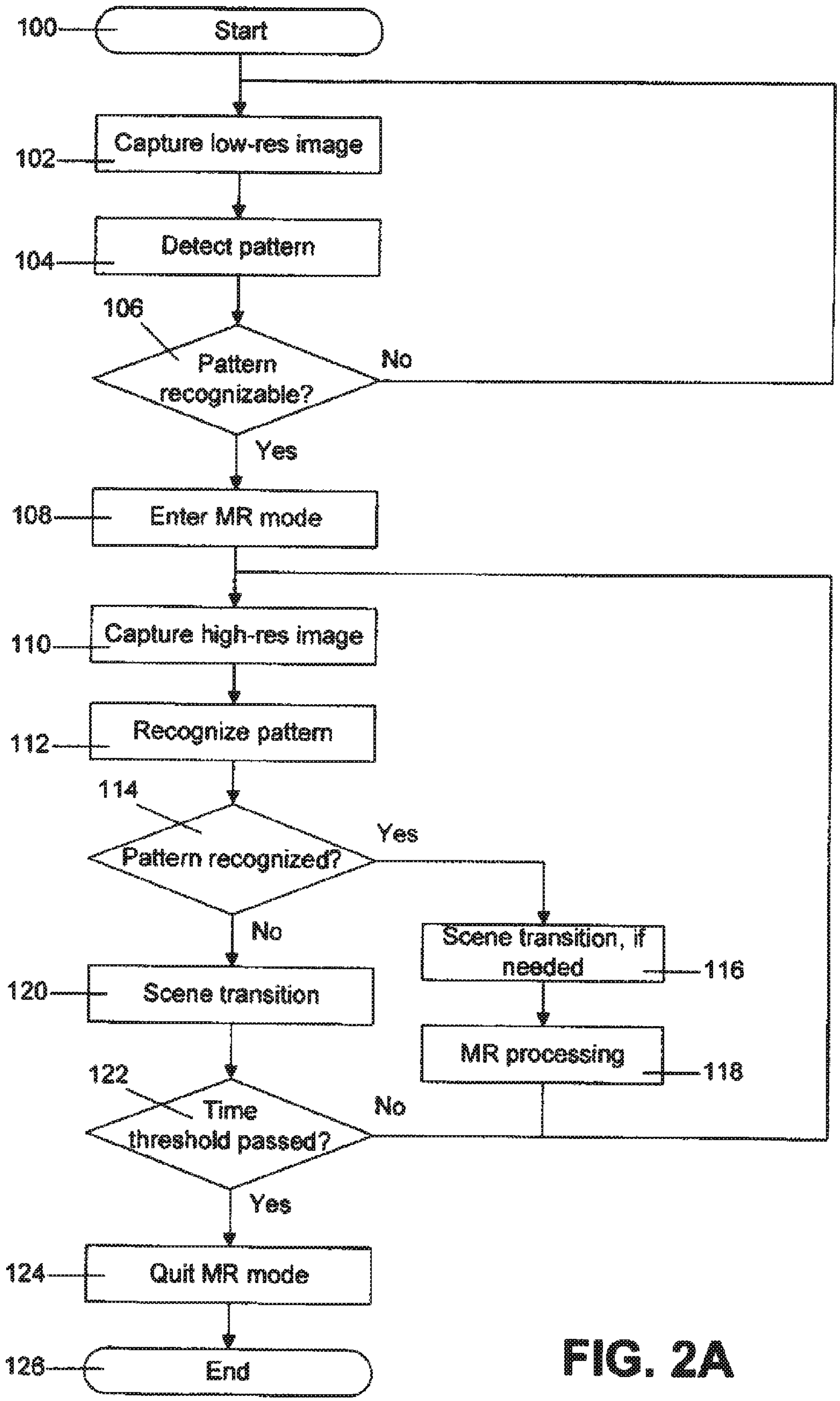

100
Start
Capture low-res image
102
Detect pattern
104
106
Pattern recognizable?
No
Yes
108
Enter MR mode
Capture high-res image
110
Recognize pattern
112
114
Pattern recognized?
Yes
No
Scene transition, if needed
116
120
Scene transition
MR processing
118
122
Time threshold passed?
No
Yes
124
Quit MR mode
126
End

FIG. 2A

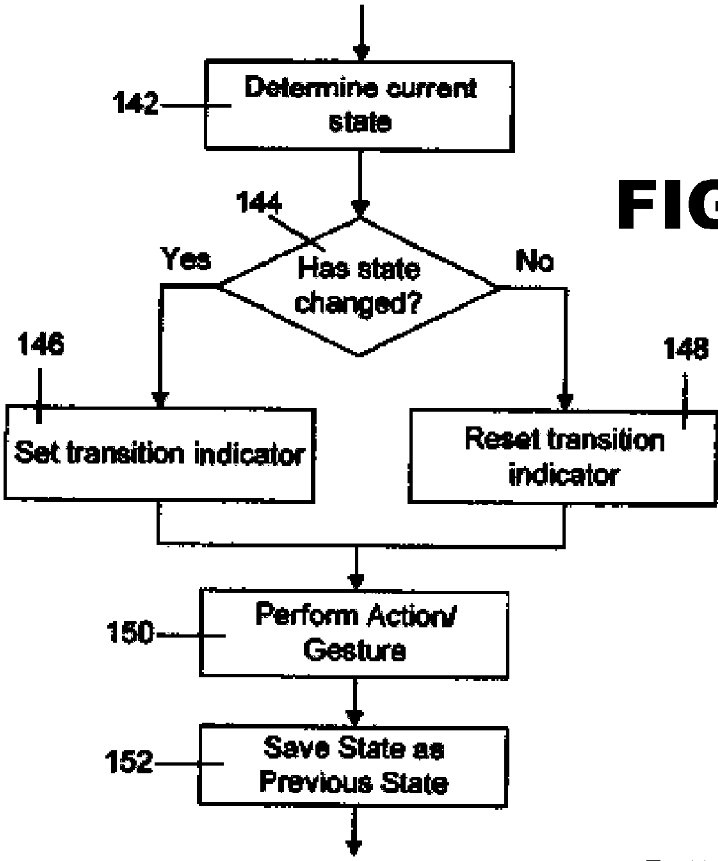

Determine current state
142
144
Has state changed?
Yes
No
146
148
Set transition indicator
Reset transition indicator
Perform Action/ Gesture
150
Save State as Previous State
152

FIG. 2B

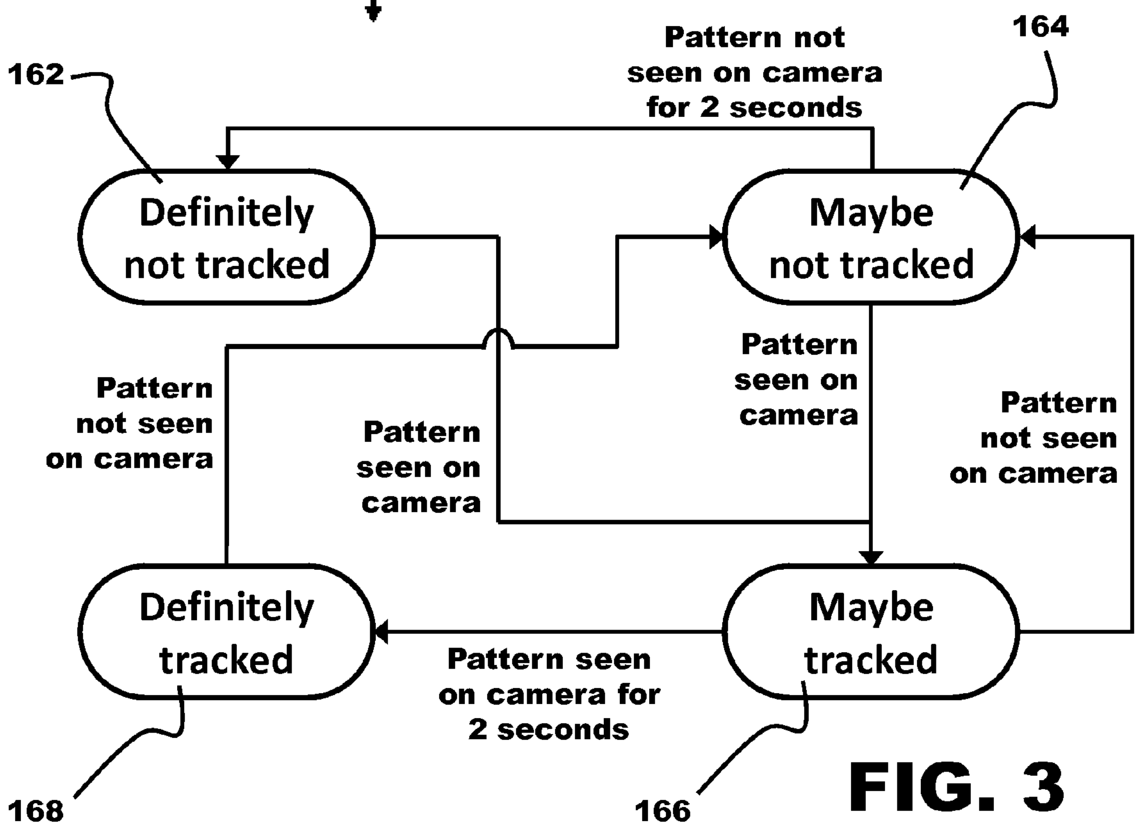

162
164
Pattern not seen on camera for 2 seconds
Definitely not tracked
Maybe not tracked
Pattern not seen on camera
Pattern seen on camera
Pattern seen on camera
Pattern not seen on camera
Definitely tracked
Maybe tracked
Pattern seen on camera for 2 seconds
168
166

FIG. 3

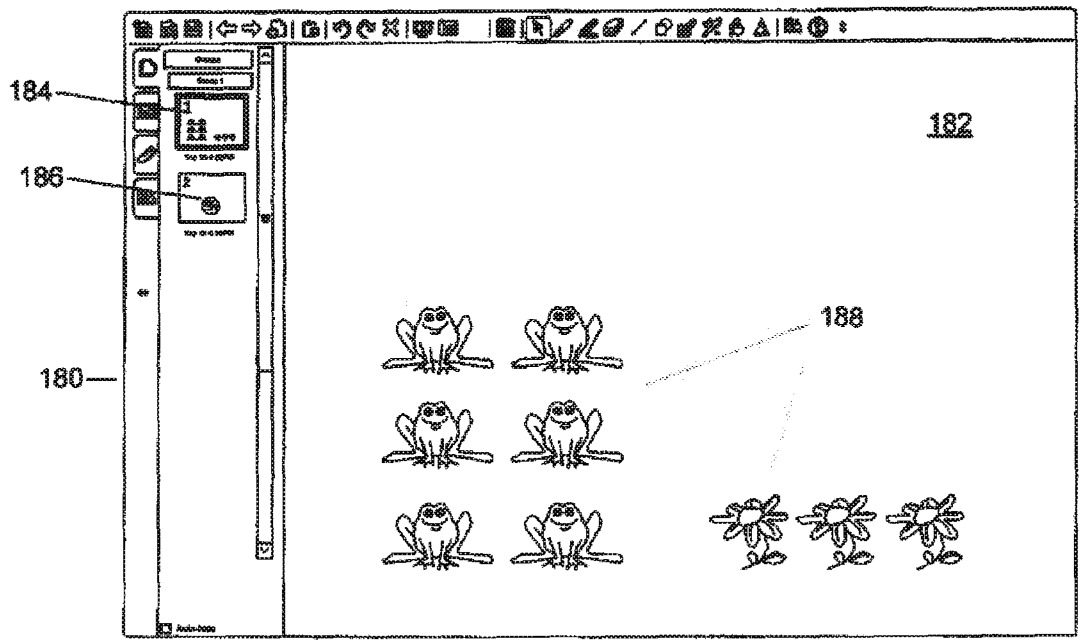
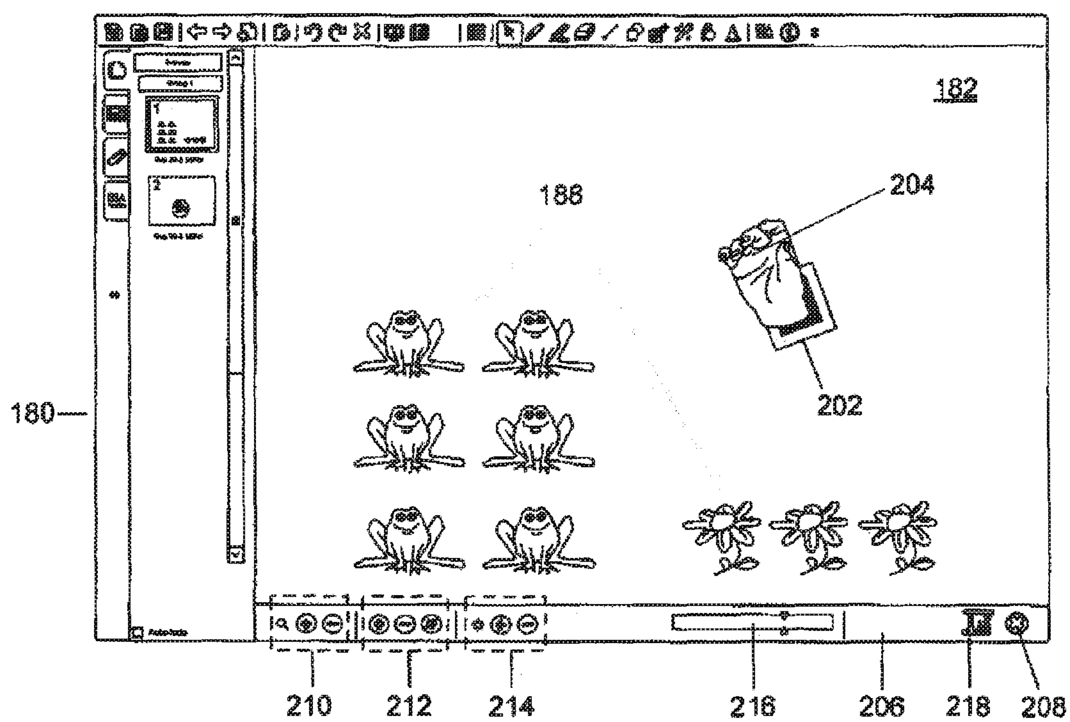

184
186
182
188
180

FIG. 4A


182
188
204
202
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206
218
208

FIG. 4B

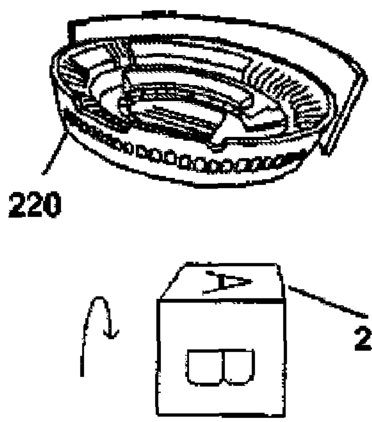


FIG. 5A

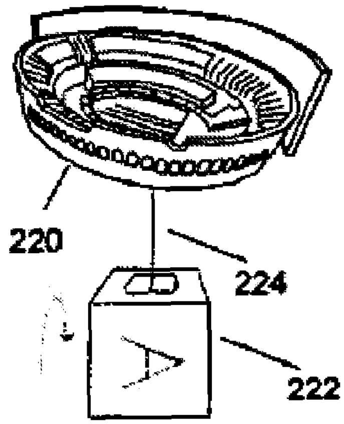


FIG. 5B

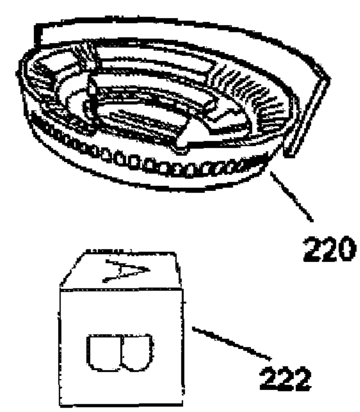


FIG. 5C

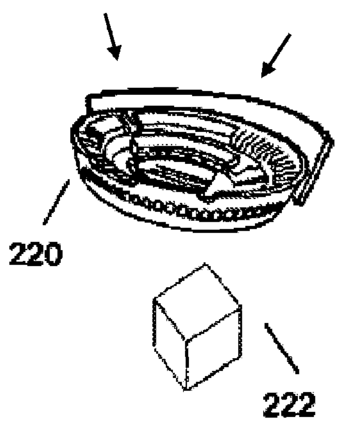


FIG. 6A

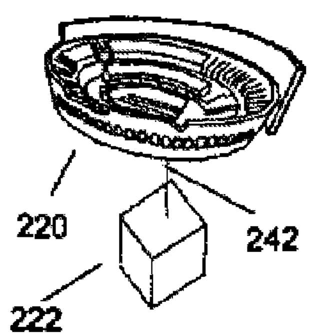


FIG. 6B

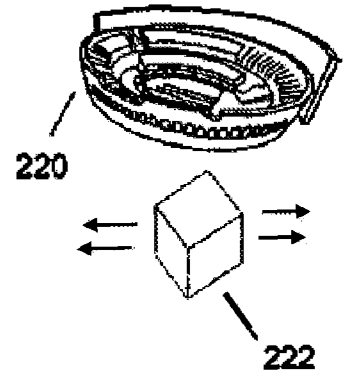


FIG. 6C

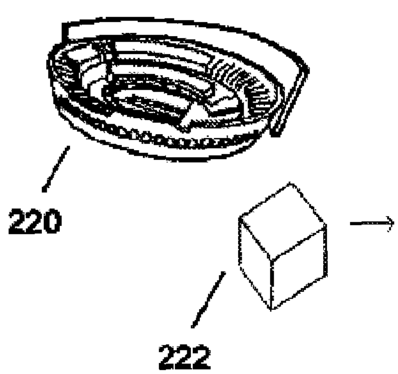


FIG. 6D

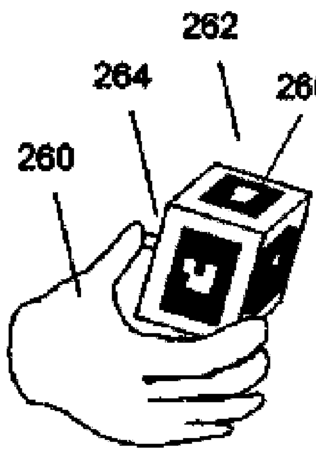


FIG. 7A

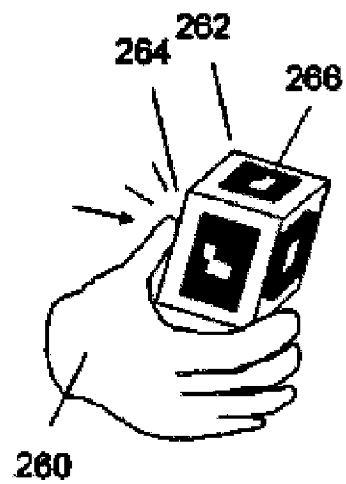


FIG. 7B

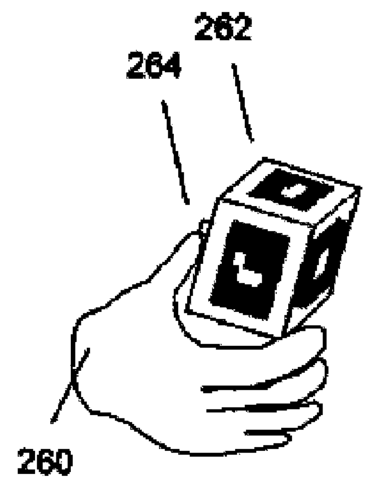


FIG. 7C

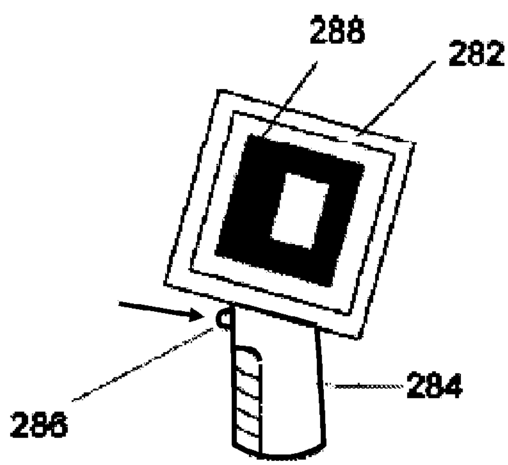


FIG. 8A

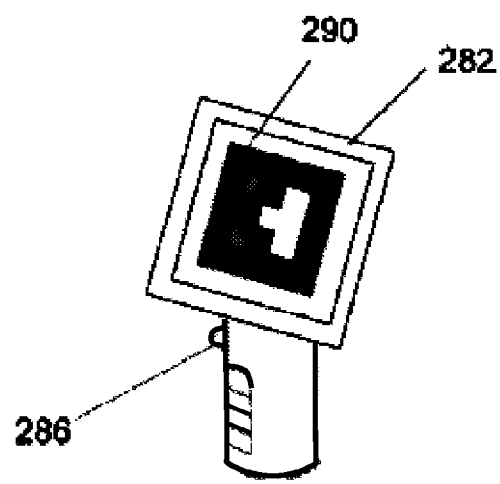


FIG. 8B

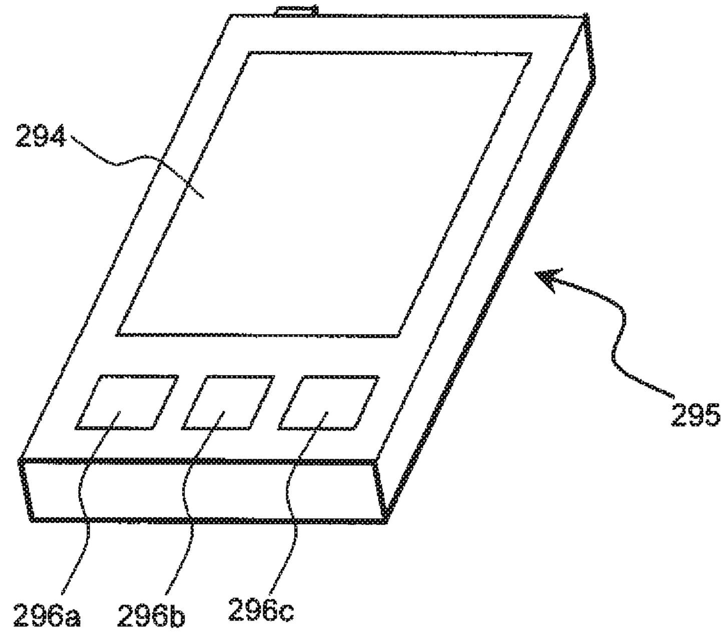

294
295
296a
296b
296c

FIG. 8C

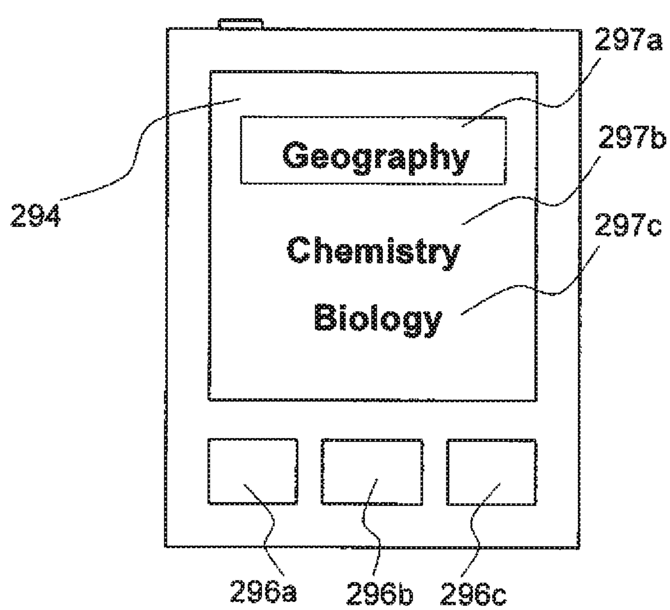

297a
297b
297c
294
Geography
Chemistry
Biology
296a
296b
296c

FIG. 8D

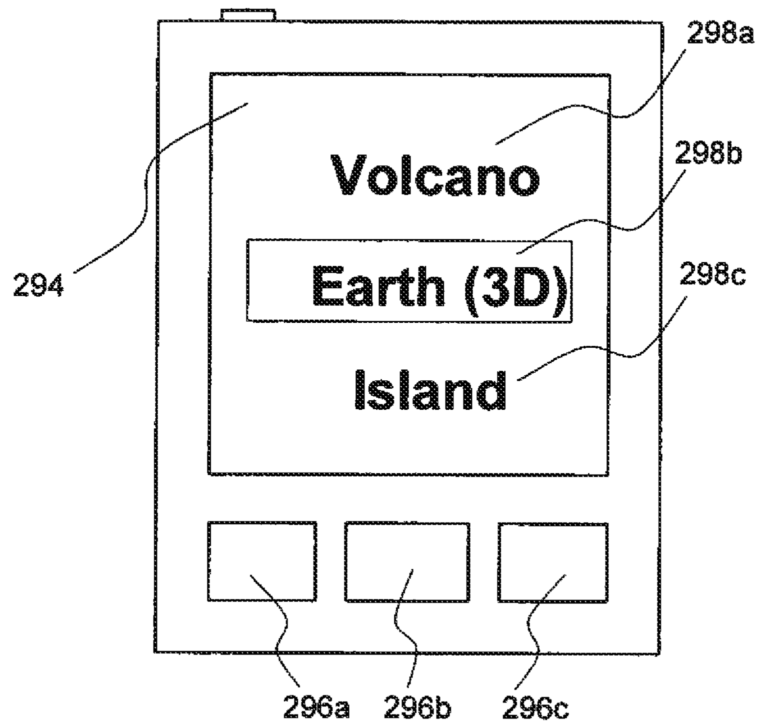

298a
298b
298c
294
Volcano
Earth (3D)
Island
296a
296b
296c

FIG. 8E

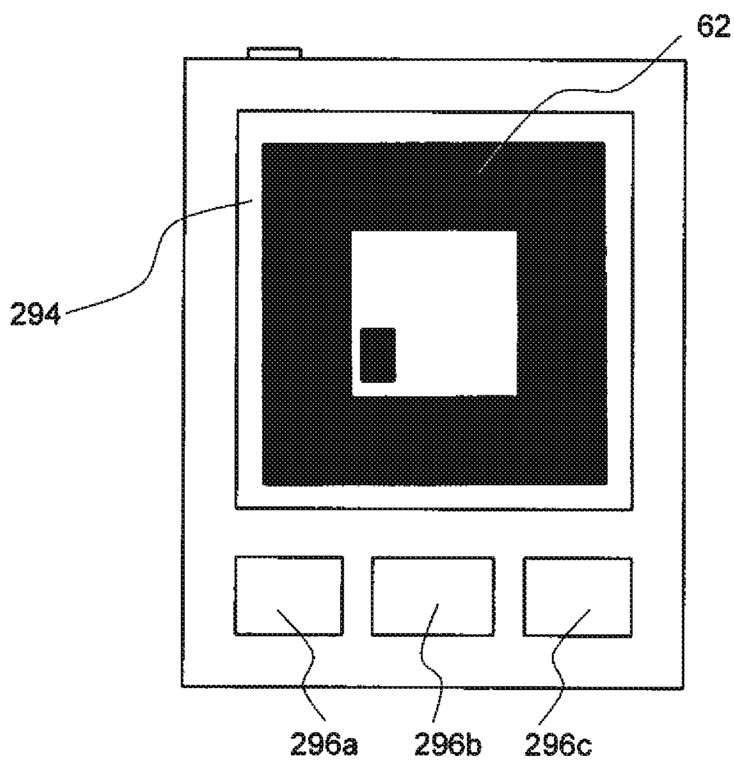

62
294
296a
296b
296c

FIG. 8F

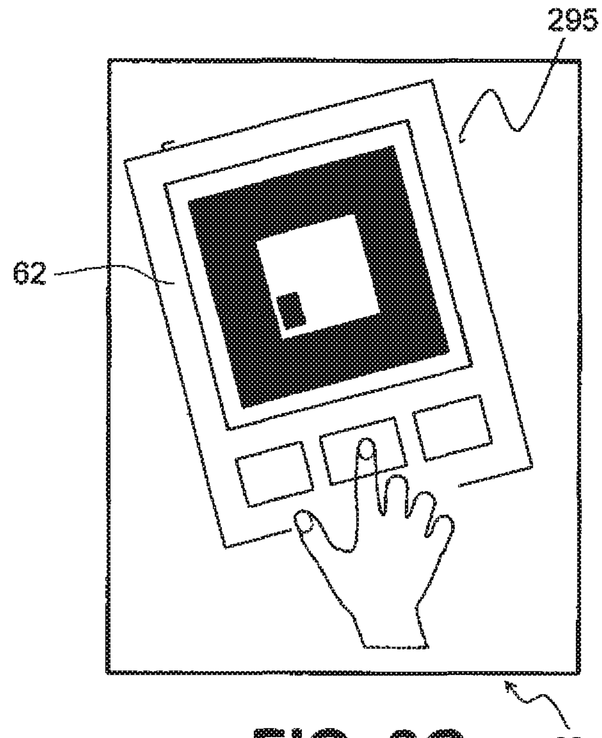


FIG. 8G

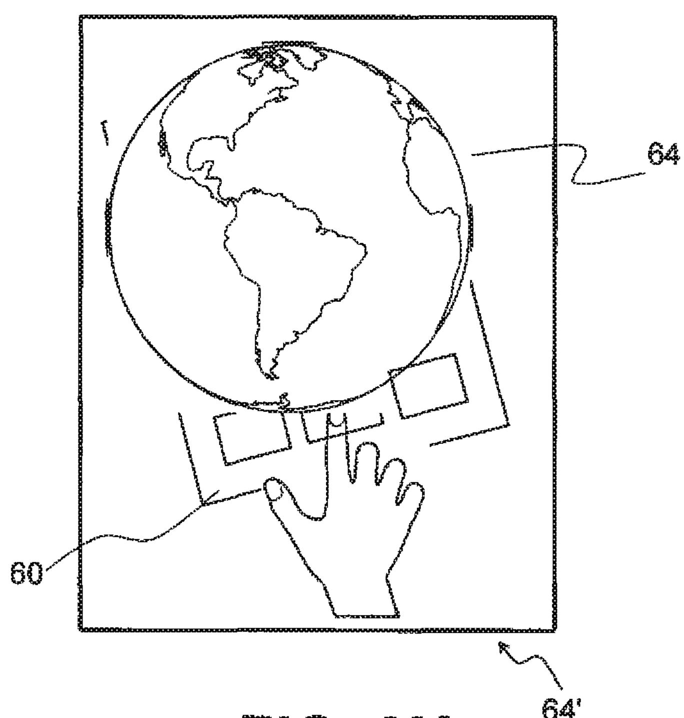


FIG. 8H

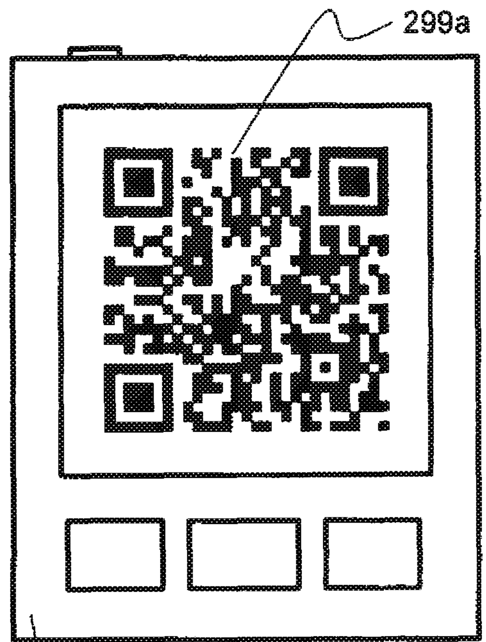


FIG. 8I

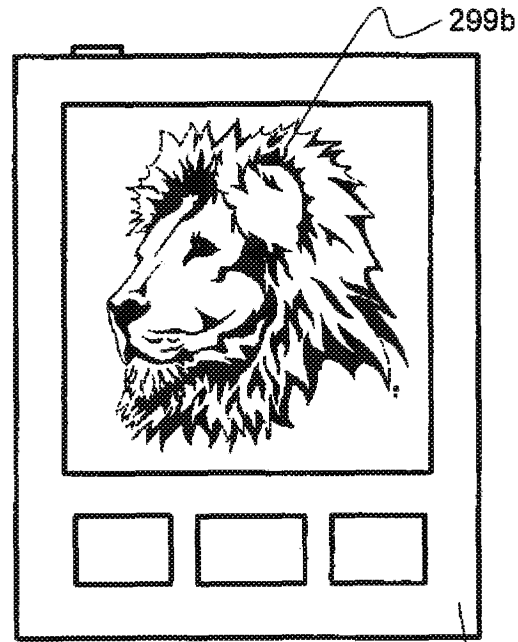


FIG. 8J

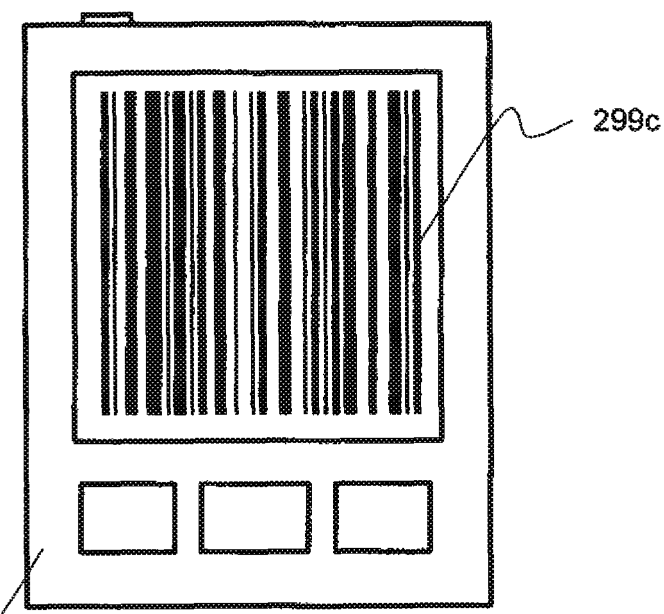


FIG. 8K

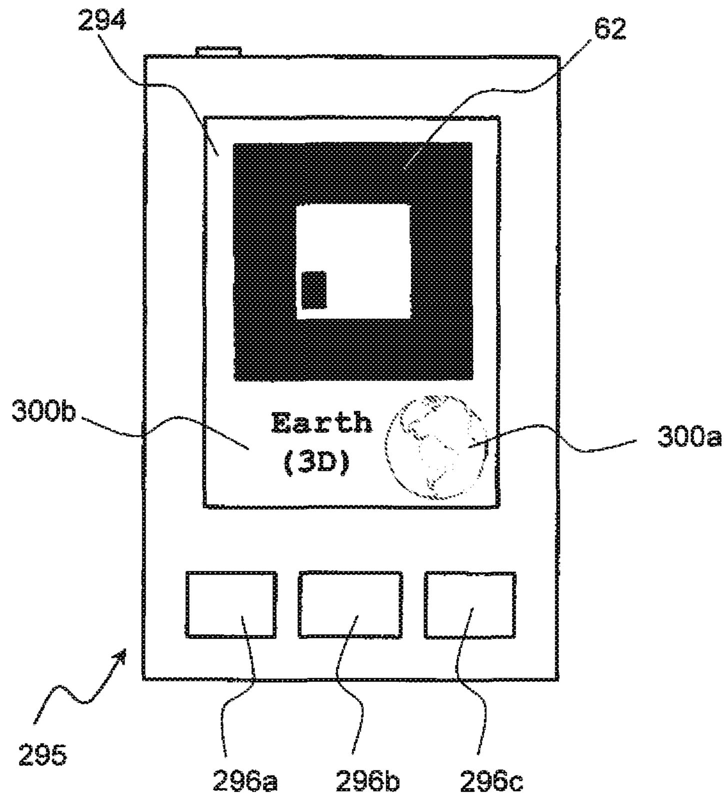

294
62
300b
Earth
(3D)
300a
295
296a
296b
296c

FIG. 8L

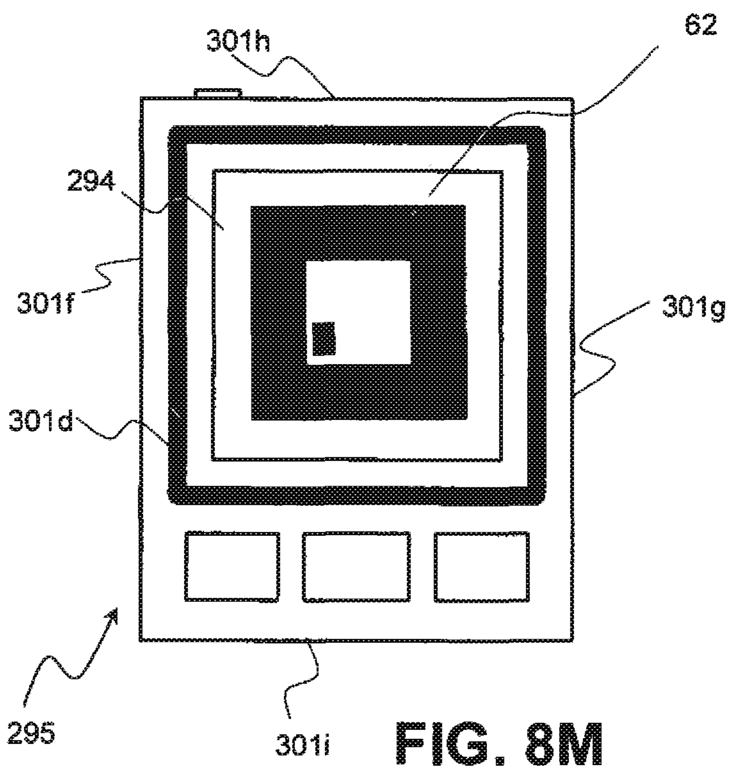

301h
62
294
301f
301g
301d
295
301i

FIG. 8M

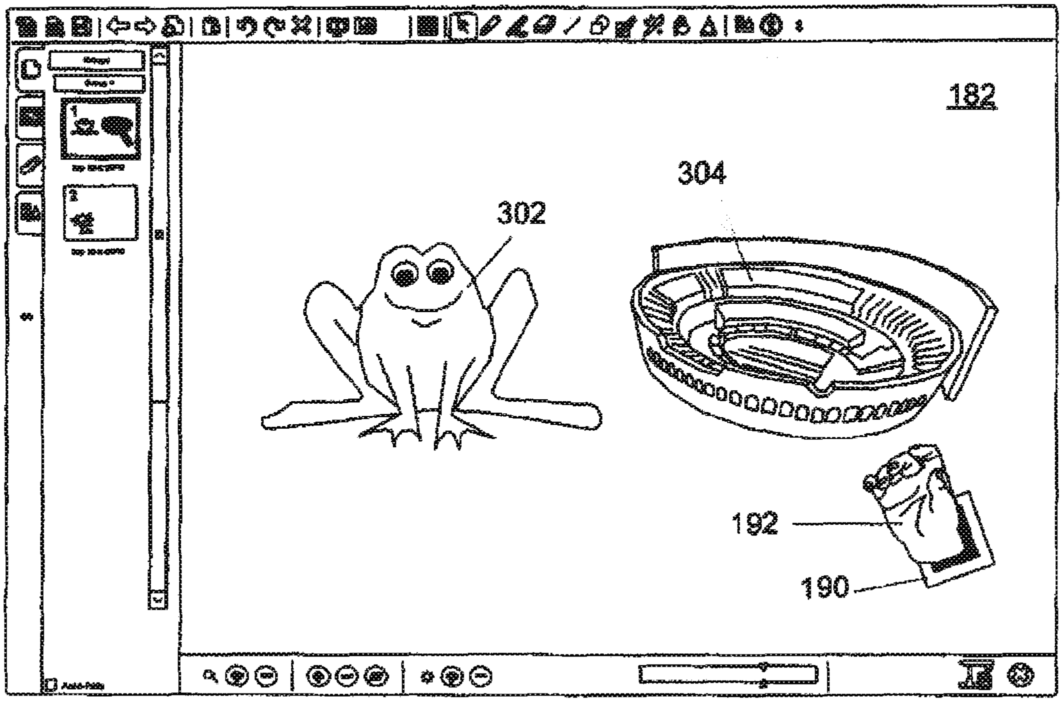


FIG. 9A

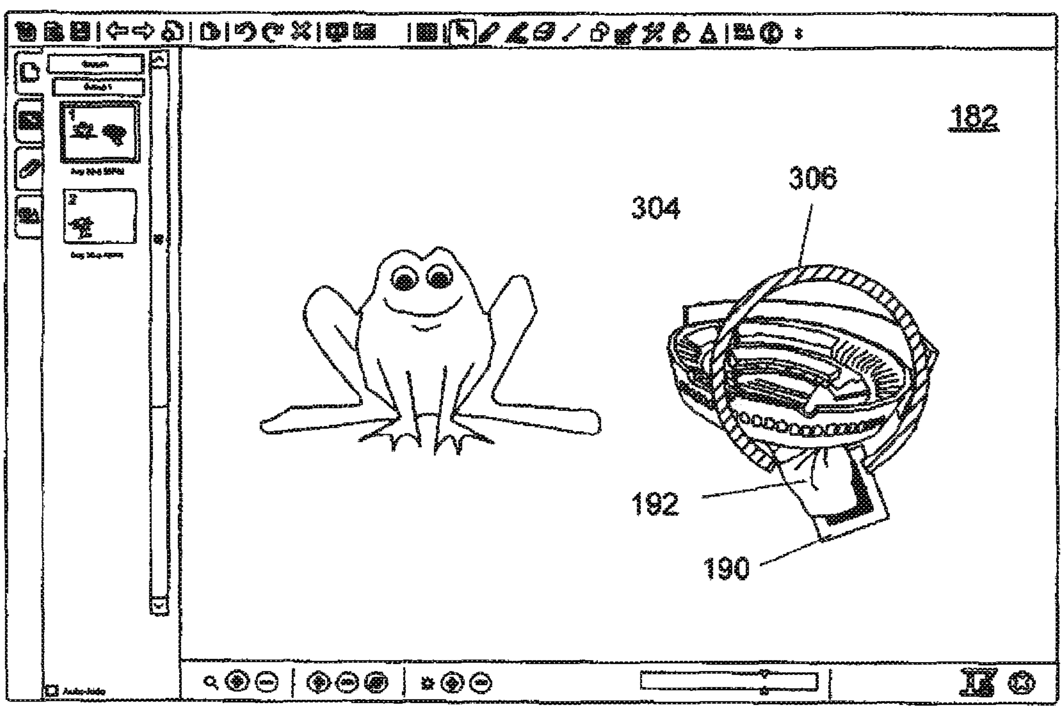


FIG. 9B

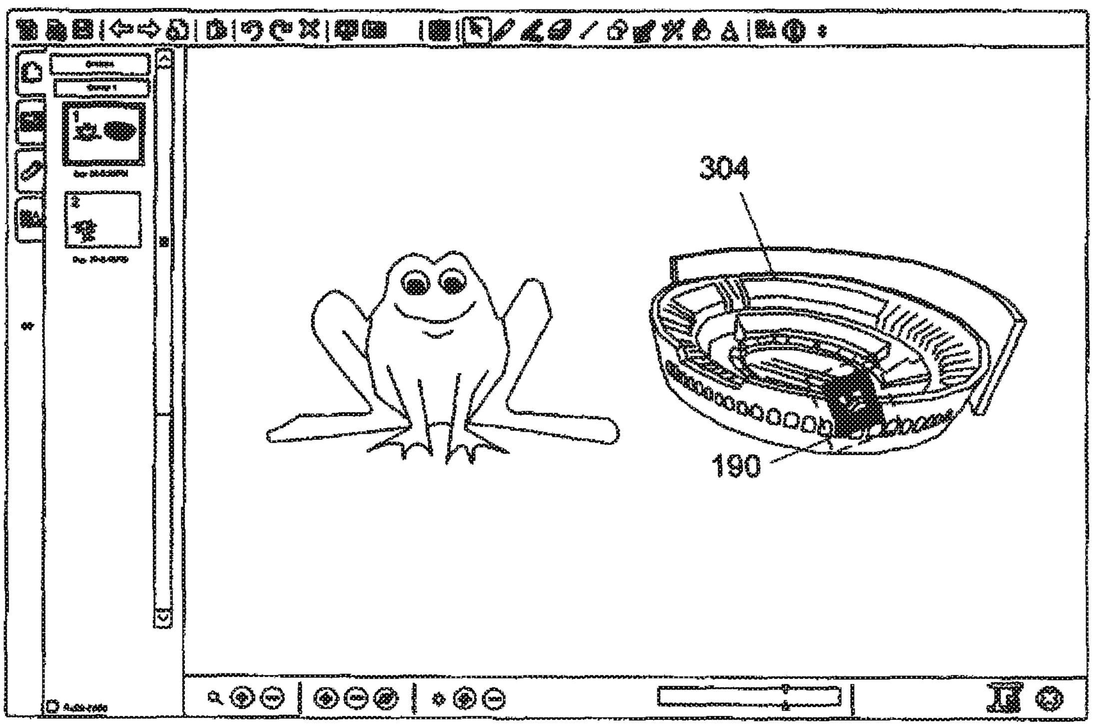


FIG. 9C

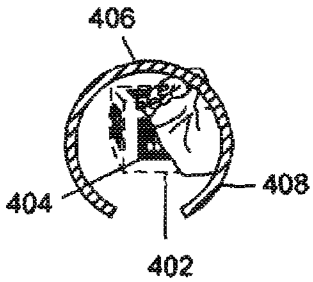


FIG. 10A

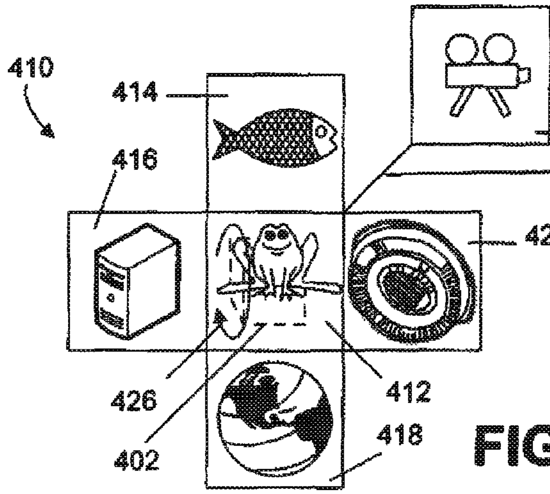


FIG. 10B

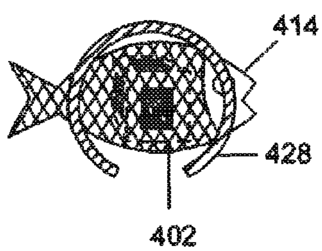


FIG. 10C

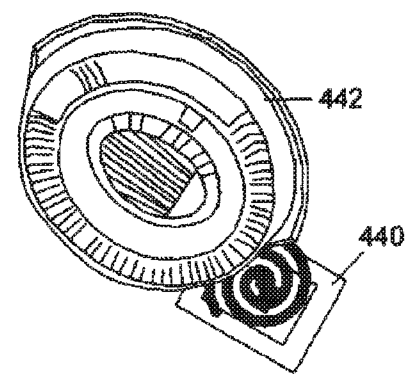


FIG. 11A

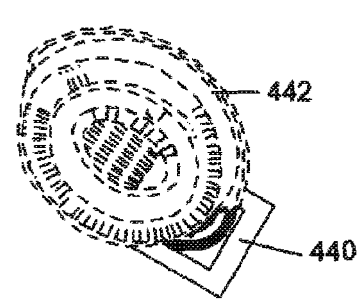


FIG. 11B

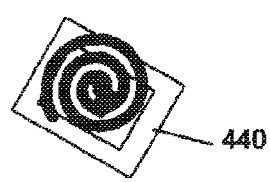


FIG. 11C

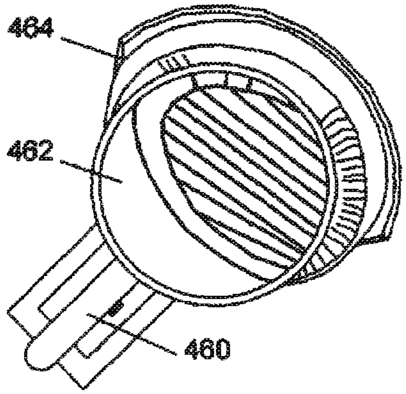


FIG. 12A

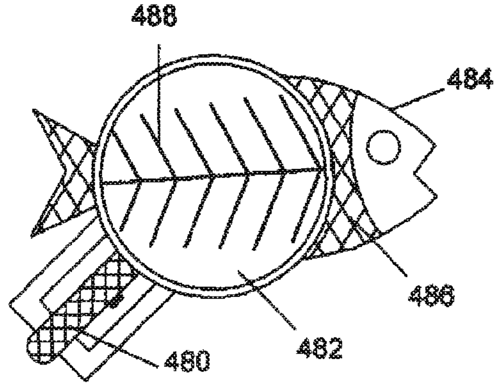


FIG. 12B

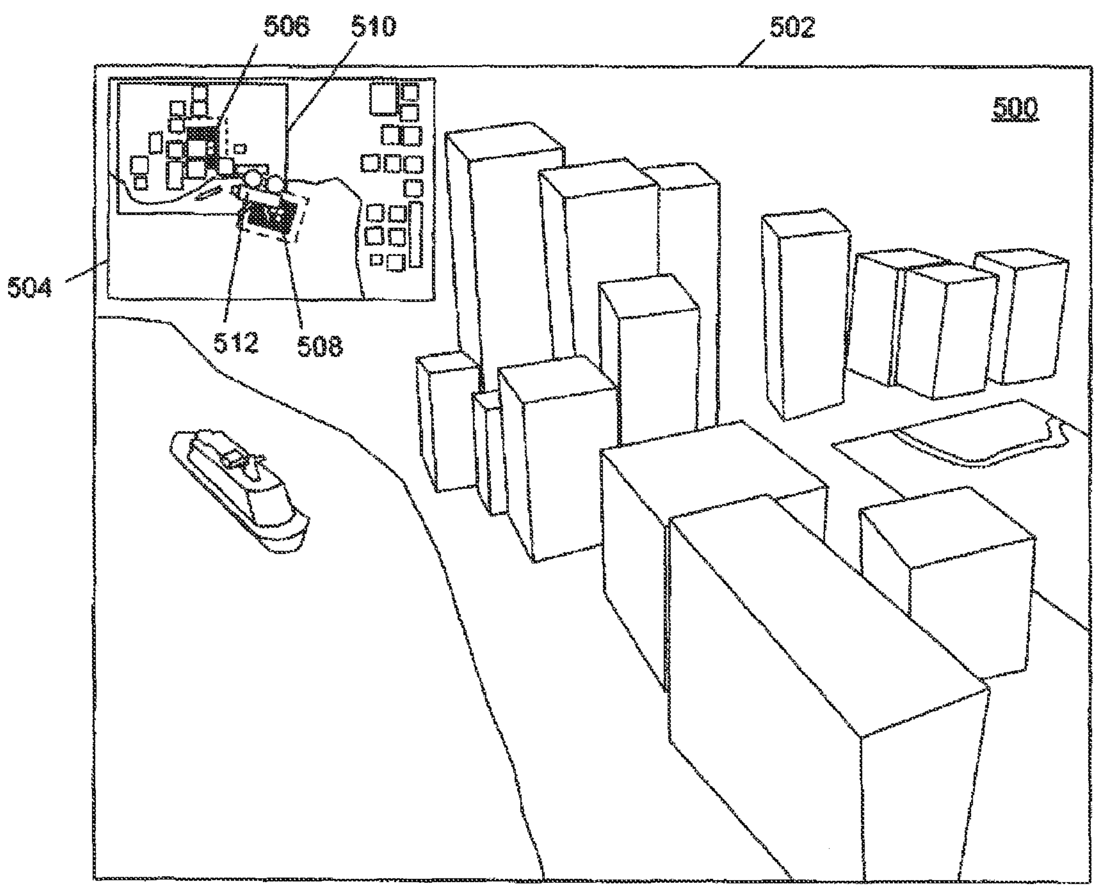


FIG. 13

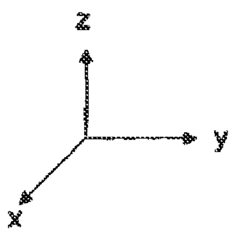


FIG. 14A

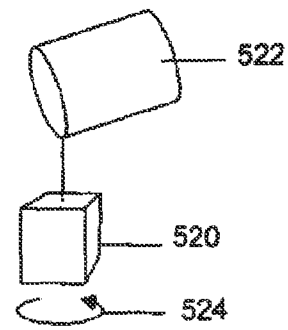


FIG. 14B

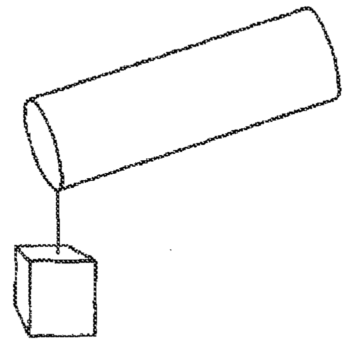


FIG. 14C

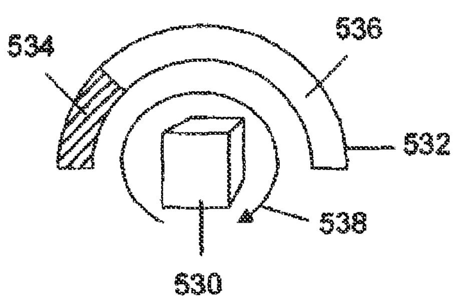


FIG. 14D

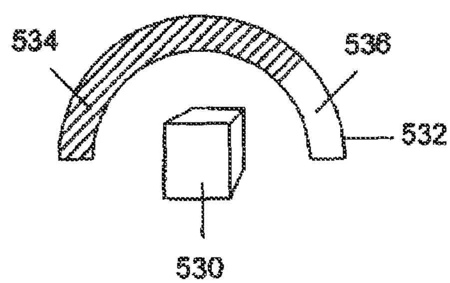


FIG. 14E

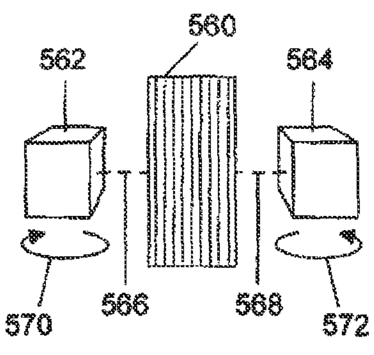


FIG. 15A

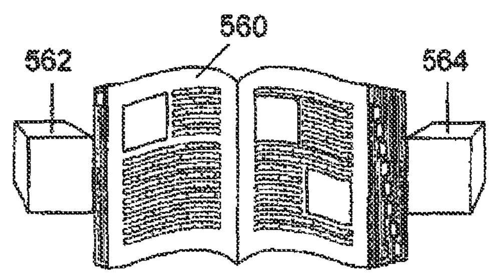


FIG. 15B

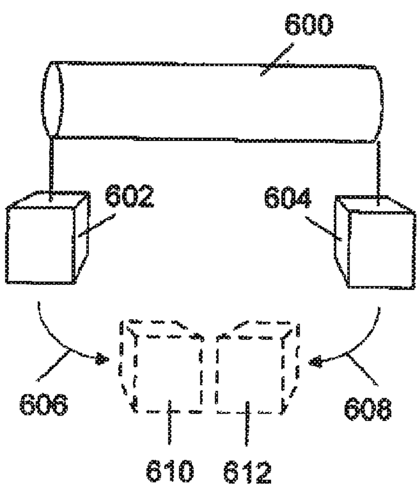


FIG. 16A

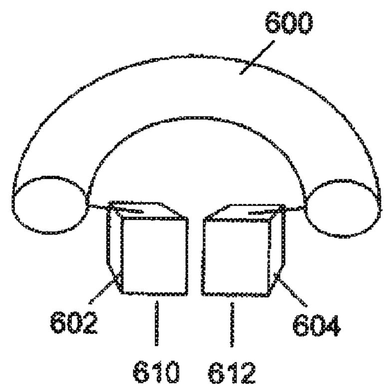


FIG. 16B

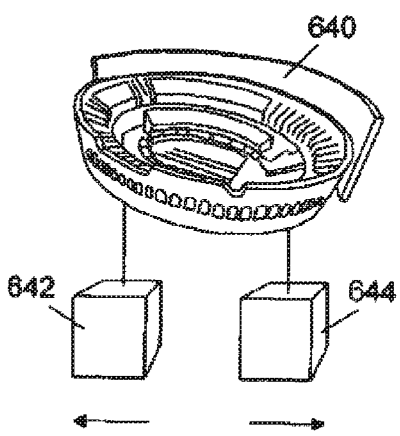


FIG. 17A

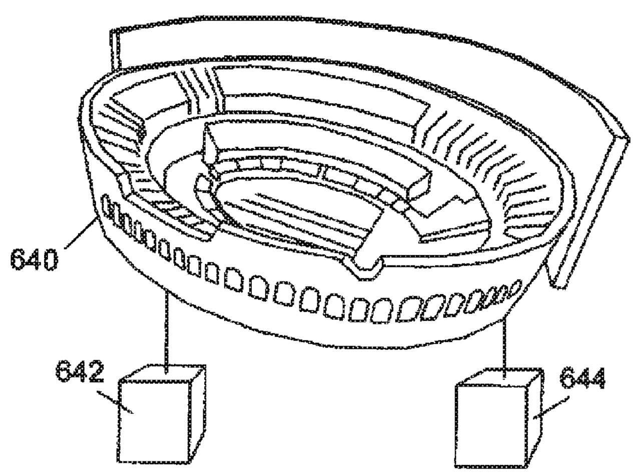


FIG. 17B

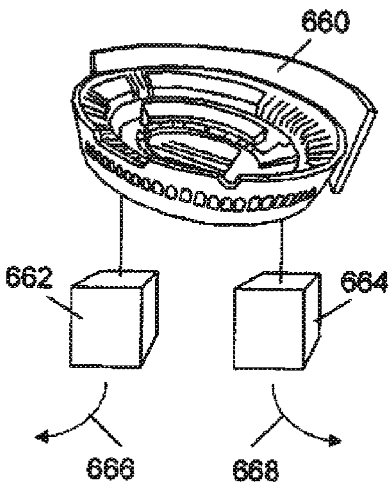


FIG. 18A

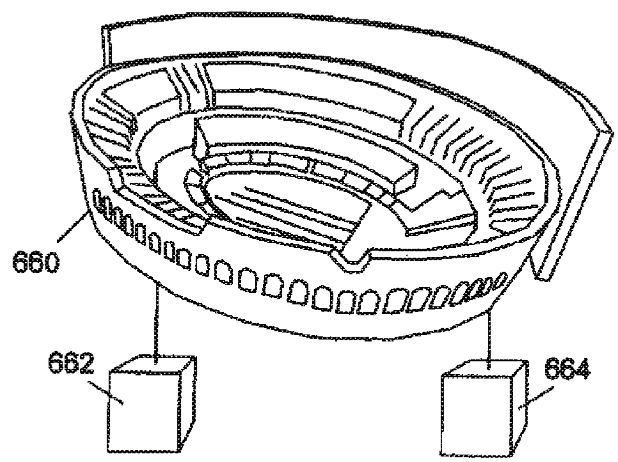


FIG. 18B

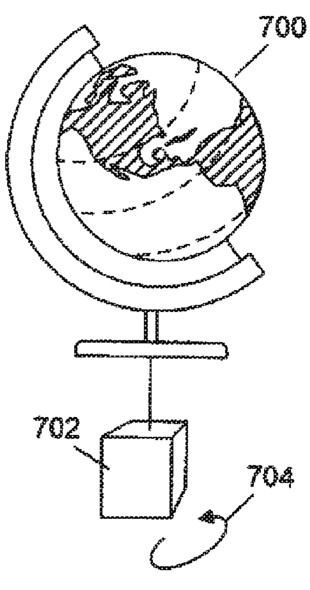


FIG. 19A

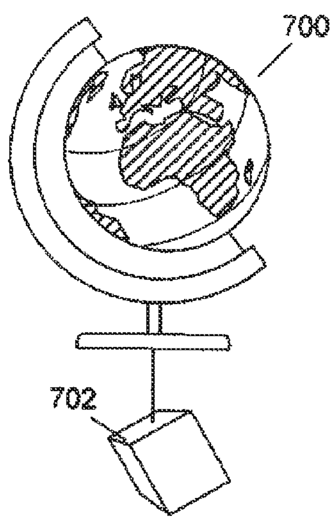
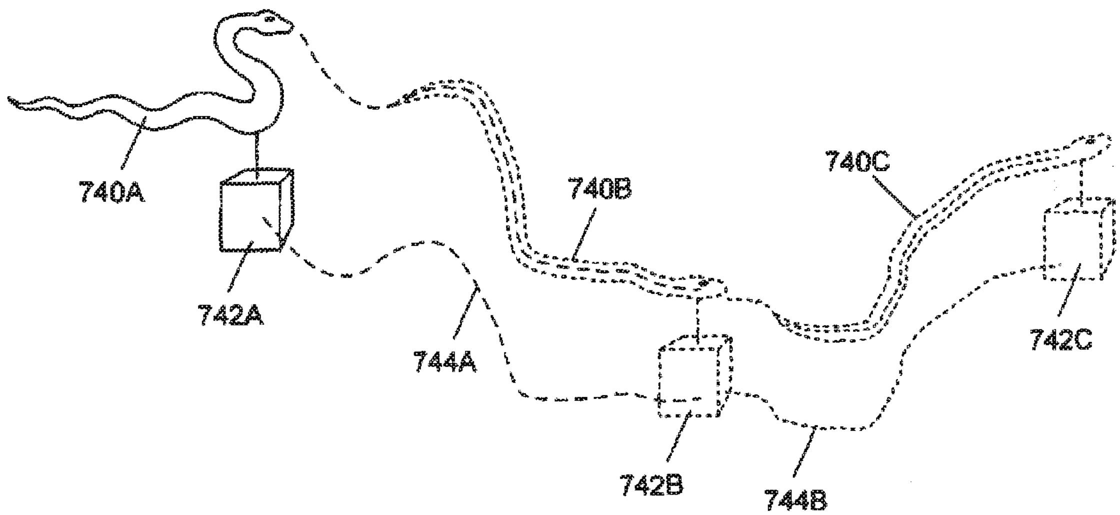
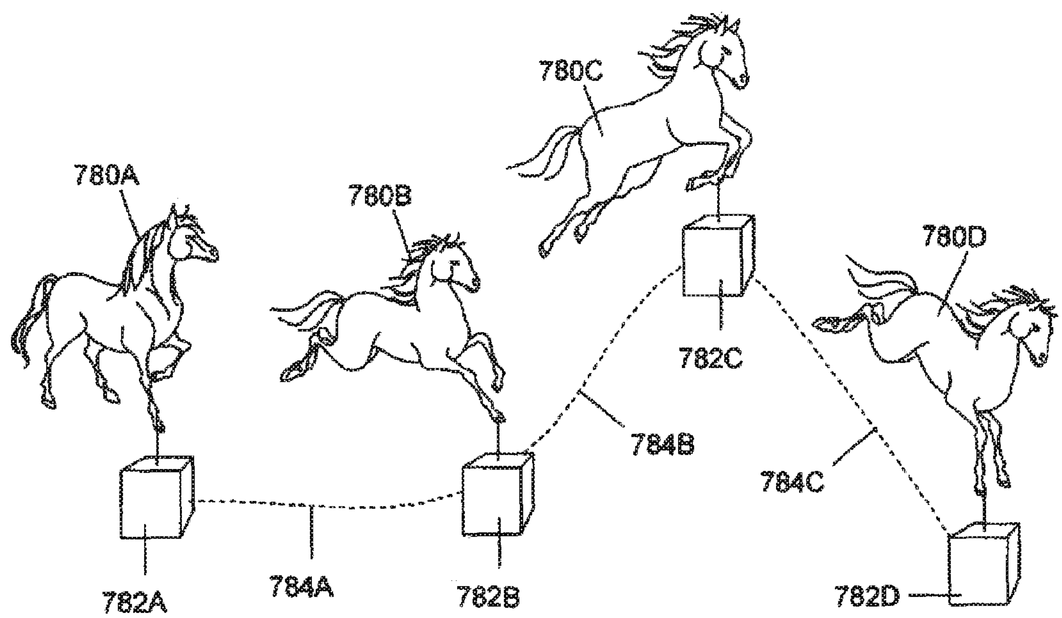


FIG. 19B



740A
742A
744A
740B
740C
742B
744B
742C

FIG. 20



780A
780B
780C
780D
782A
784A
782B
784B
782C
784C
782D

FIG. 21

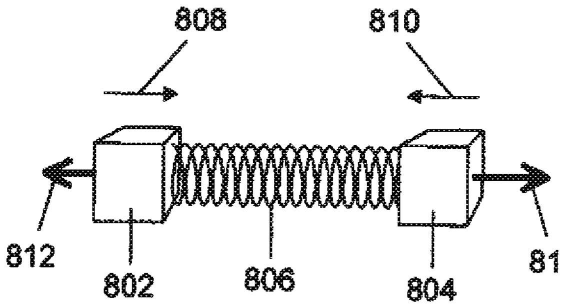


FIG. 22A

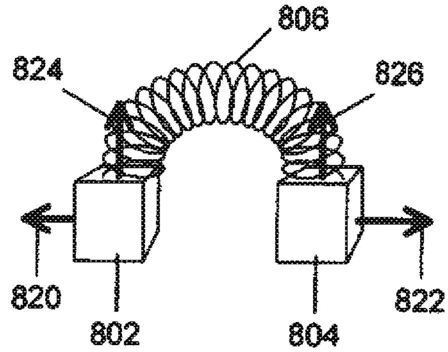


FIG. 22B

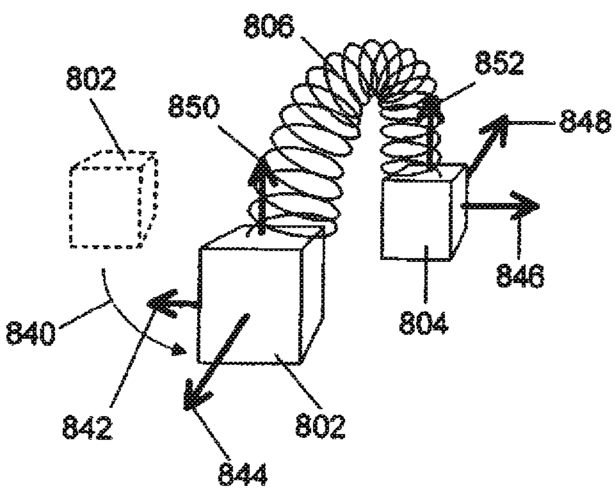


FIG. 22C

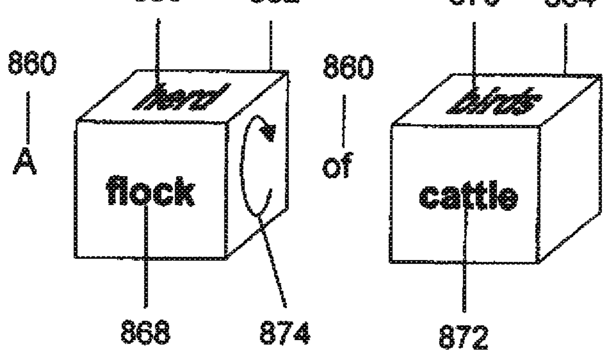


FIG. 23

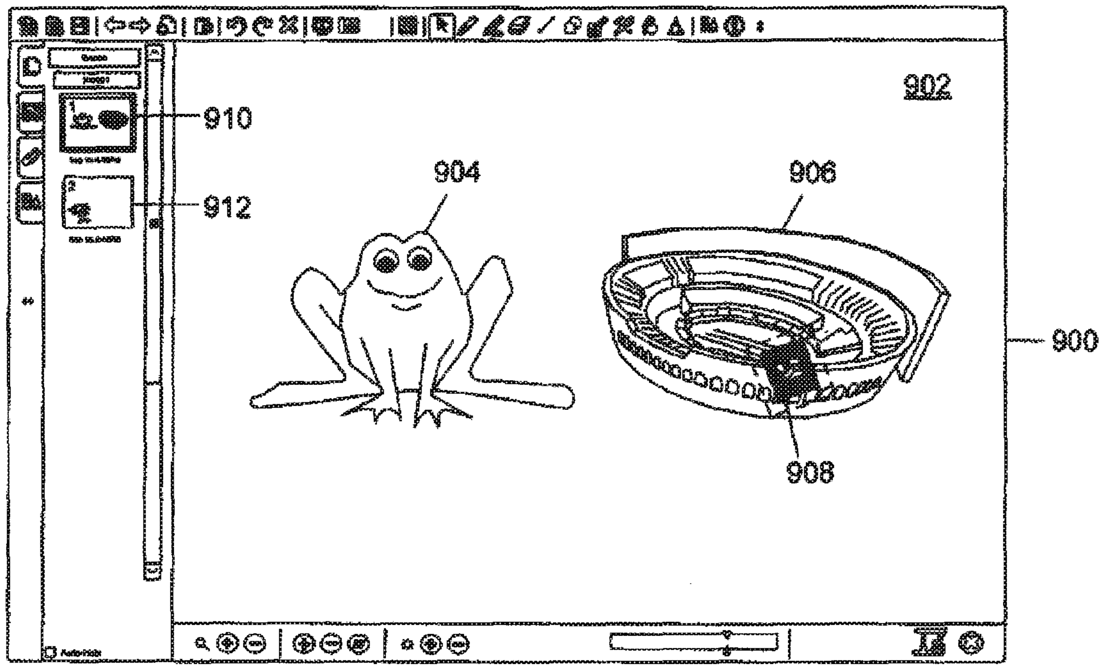


FIG. 24A

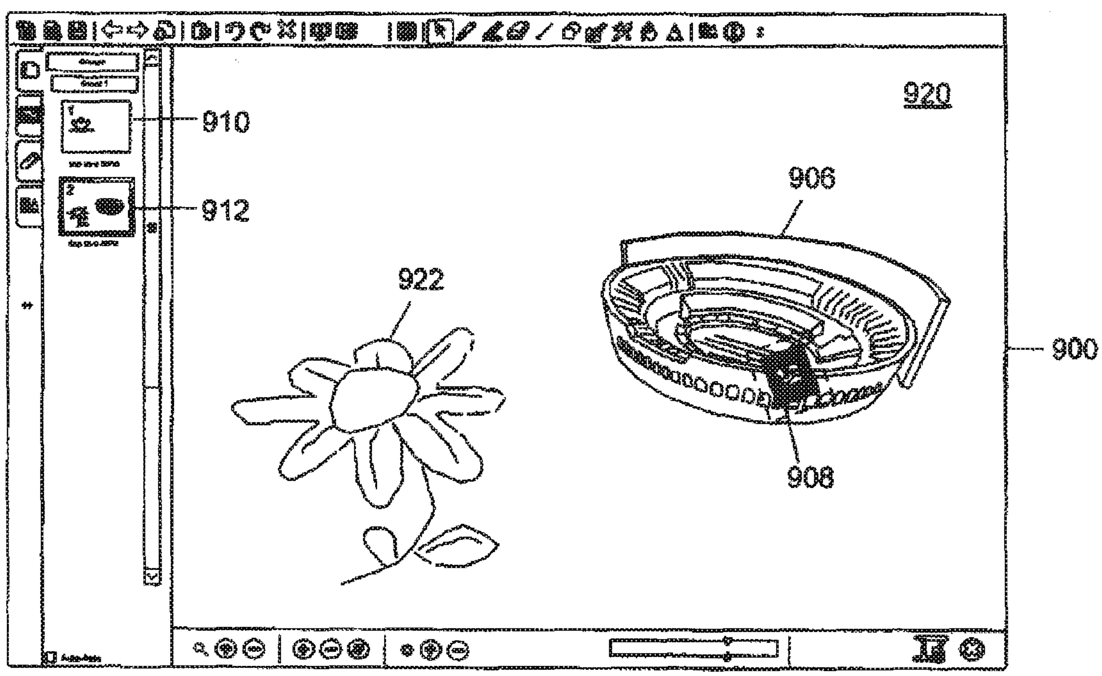


FIG. 24B

INTERACTIVE INPUT SYSTEM HAVING A 3D INPUT SPACE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/470,409 to Exner filed on Mar. 31, 2011 for an invention entitled "Interactive Input System Having A 3D Input Space", the entire content of which is incorporated herein by reference.

FIELD OF THE INVENTION

The present invention generally relates to interactive input systems and in particular, to an interactive input system having a three-dimensional (3D) input space and to 3D tools and gestures for interacting in mixed reality environments.

BACKGROUND OF THE INVENTION

Mixed reality or augmented interactive input systems are known in the art. Some existing augmented interactive input systems make use of a document camera to track physical objects such as cubes and flashcards that comprise recognizable patterns. Digital content is superimposed on top of the images captured by the document camera. The direct association of the physical objects to digital content allows users to manipulate the digital content through manipulation of the physical objects. Unfortunately, these augmented interactive input systems have only permitted the position and orientation of physical objects to be tracked. As a result, user manipulations of digital content in this scenario have been limited to translations and rotations of physical objects. By only permitting the position and orientation of the physical objects to be tracked, interactions such as clicking a button or opening a menu have been difficult to realize without use of an external input device such as a mouse or keyboard.

Another problem that occurs in existing augmented interactive input systems is the temporary loss of physical objects that are being tracked. When an augmented interactive input system loses track of a physical object and then regains tracking of the physical object, the associated digital content shown on the display disappears and then quickly re-appears, causing unwanted flickering.

Another problem with these augmented interactive input systems is that they generally employ physical markers, such as, paper-based markers, which are difficult to identify under poor ambient lighting conditions. Additionally, proper identification of the marker may be severely affected by light reflecting off of the surface of the marker, or by shadows or other occlusions of portions of the marker.

The publication entitled "Occlusion based Interaction Methods for Tangible Augmented Reality Environments," authored by Lee et al. and published in the Proceedings of the 2004 ACM SIGGRAPH international conference on Virtual Reality continuum and its applications in industry (pages 419-426, 2004), discloses an occlusion based interaction system and method for interacting with two-dimensional (2D) digital objects in a camera-based tangible augmented reality environment. A marker comprising a set of patterns is imaged by a camera, and patterns on the marker are recognized. When a user uses a finger to manipulate the marker and the finger occludes at least one pattern on the marker, the interaction system determines which pattern has been occluded, and then performs a 2D action (e.g., clicking a button or opening a menu) accordingly. Because multiple patterns are required, either the marker has to be sufficiently large so as to accommodate the patterns, making the marker, as a physical object, difficult to manipulate, or the patterns have to be small, which may increase the failure rate of pattern recognition.

As will be appreciated, improvements in mixed reality or augmented interactive input systems are desired. It is therefore an object of the following to provide a novel interactive input system having a three-dimensional input space.

SUMMARY OF THE INVENTION

Accordingly, in one aspect there is provided an interactive input system comprising computing structure; and an input device detecting at least one electronic device displaying a recognizable pattern within a three-dimensional (3D) input space and providing output to said computing structure, wherein said computing structure processes the output of the input device to recognize the pattern displayed by the at least one electronic device in the 3D input space; detect the state of the at least one electronic device; and modify image data by applying a transition to digital content associated with the displayed pattern based on the detected state of the at least one electronic device.

According to another aspect there is provided an interactive input system comprising computing structure; and an input device detecting at least one electronic device displaying a recognizable pattern within a three-dimensional (3D) input space and providing output to said computing structure, wherein said computing structure processes the output of the input device to recognize the pattern displayed by the at least one electronic device in the 3D input space; determine when the location of the pattern within the 3D input space and the location of digital content in an image presented on a display surface satisfy defined criteria; and associate the pattern to the digital content.

According to another aspect there is provided an apparatus comprising a processing device receiving data representing an electronic device displaying a recognizable pattern positioned within a three-dimensional (3D) input space; and memory storing computer program code executable by the processing device, the processing device communicating with the memory and executing the program code and causing the apparatus at least to recognize the pattern carried by the electronic device in the 3D input space; determine when the location of the pattern within the 3D input space and the location of digital content in an image presented on a display surface satisfy defined criteria; and associate the pattern to the digital content.

According to still yet another aspect there is provided a method comprising detecting a unique pattern displayed by an electronic device positioned within a three-dimensional input space; determining when the pattern is positioned within the input space at a location within a threshold distance of a location corresponding to digital content within a presented image; and associating the pattern to the digital content so that manipulation of the electronic device within the input spaces manipulates the digital content.

Advantageously, data representing a plurality of recognizable patterns can be stored locally in digital libraries on the electronic device, or accessed remotely via communication networks, and such libraries can be easily and rapidly accessed, and searched. Furthermore, use of the electronic device to display the patterns does not exhibit problems associated with paper-based markers, such as, legibility issues due to lighting conditions, wear and tear, etc.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments will now be described more fully with reference to the accompanying drawings in which:

FIG. 1A is a partial perspective, schematic diagram of an interactive input system having a three-dimensional (3D) input space;

FIG. 1B is a perspective view of a 3D input device forming part of the interactive input system of FIG. 1A showing the 3D input space imaged thereby;

FIG. 1C is an image of the 3D input space captured by the 3D input device of FIG. 1B;

FIG. 2A is a flowchart showing steps performed during manipulation of digital content by tracking physical objects in the 3D input space;

FIG. 2B is a flowchart showing steps performed during mixed reality processing;

FIG. 3 shows the possible states of a physical object in the 3D input space and transitions of the possible states;

FIGS. 4A and 4B illustrate an example of an application program window transitioning from a non-mixed reality mode to a mixed-reality mode;

FIGS. 5A to 5C illustrate a content selection technique that selects digital content in response to rotation of a physical object in the 3D input space;

FIGS. 6A to 6D illustrate an alternative content selection technique that selects digital content by attracting digital content to a physical object in the 3D input space;

FIGS. 7A to 7C illustrate yet another content selection technique that selects digital content in response to a cube-shaped physical object having liquid crystal display (LCD) panels in the 3D input space;

FIGS. 8A and 8B illustrate still yet another content selection technique that selects digital content in response to a physical object having an LCD panel and a handle in the 3D input space;

FIGS. 8C to 8M illustrate still yet another content selection technique that selects digital content in response to an electronic device having a display in the 3D input space;

FIGS. 9A to 9C illustrate a dwelling gesture for selecting digital content in response to a physical object in the 3D input space;

FIGS. 10A to 10C illustrate manipulation of a physical object in the 3D input space to open a menu and select an item thereof;

FIGS. 11A to 11C illustrate manipulation of a physical object in the 3D input space to erase digital content;

FIG. 12A illustrates manipulation of a physical object in the 3D input space to zoom in on a portion of digital content;

FIG. 12B illustrates manipulation of a physical object in the 3D input space to expose a second layer of digital content;

FIG. 13 illustrates manipulation of two physical objects in the 3D input space to view a portion of digital content;

FIGS. 14A to 14E illustrate a rotation method for modifying characteristics of digital content based on the rotation axis of a physical object in the 3D input space;

FIGS. 15A and 15B illustrate an alternative rotation method for opening an ebook in response to rotation of two physical objects in the 3D input space;

FIGS. 16A and 16B illustrate manipulation of two physical objects in the 3D input space to bend digital content;

FIGS. 17A and 17B illustrate manipulation of two physical objects in the 3D input space to zoom digital content;

FIGS. 18A to 19B show examples where restrictions are applied when manipulating digital content using physical objects in the 3D input space;

FIGS. 20 and 21 illustrate an animation method for manipulating digital content based on the motion of a physical object in the 3D input space;

FIGS. 22A to 22C show an example of a mixed reality application for illustrating physics principles by manipulating two physical objects in the 3D input space;

FIG. 23 shows a method of manipulating a physical object in the 3D input space to answer a question; and

FIGS. 24A and 24B illustrate a method of switching a content page in the mixed reality mode.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Turning now to FIG. 1A, an interactive input system having a three-dimensional (3D) input space is shown and is generally identified by reference numeral 20. Interactive input system 20 allows a user to inject input such as digital ink, mouse events, commands, etc. into an executing application program. In this embodiment, interactive input system 20 comprises a two-dimensional (2D) input device in the form of an interactive board 22 mounted on a vertical support surface such as for example, a wall surface or the like. Interactive board 22 comprises a generally planar, rectangular interactive surface 24 that is surrounded about its periphery by a bezel 26. A boom assembly 32 is also mounted on the support surface above the interactive board 22. Boom assembly 32 supports a short-throw projector 38 such as that sold by SMART Technologies ULC of Calgary, Alberta, assignee of the subject application, under the name "SMART Unifi 45", which projects an image, such as for example, a computer desktop, onto the interactive surface 24.

The interactive board 22 employs machine vision to detect one or more pointers brought into a region of interest in proximity with the interactive surface 24. The interactive board 22 communicates with a general purpose computing device 28 executing one or more application programs via a universal serial bus (USB) cable 30 or other suitable wired or wireless communication link. Computing device 28 processes the output of the interactive board 22 and adjusts image data that is output to the projector 38, if required, so that the image presented on the interactive surface 24 reflects pointer activity. In this manner, the interactive board 22, computing device 28 and projector 38 allow pointer activity proximate to the interactive surface 24 to be recorded as writing or drawing or used to control execution of one or more application programs executed by the computing device 28.

The bezel 26 is mechanically fastened to the interactive surface 24 and comprises four bezel segments that extend along the edges of the interactive surface 24. In this embodiment, the inwardly facing surface of each bezel segment comprises a single, longitudinally extending strip or band of retro-reflective material. To take best advantage of the properties of the retro-reflective material, the bezel segments are oriented so that their inwardly facing surfaces lie in a plane generally normal to the plane of the interactive surface 24.

A tool tray 48 is affixed to the interactive board 22 adjacent the bottom bezel segment using suitable fasteners such as for example, screws, clips, adhesive etc. As can be seen, the tool tray 48 comprises a housing having an upper surface configured to define a plurality of receptacles or slots. The receptacles are sized to receive one or more pen tools 40 as well as an eraser tool (not shown) that can be used to interact with the interactive surface 24. Control buttons (not shown) are also provided on the upper surface of the tool tray housing to enable a user to control operation of the interactive input system 20. Further specifies of the tool tray 48 are described in International PCT Application Publication No. WO 2011/085486, filed on Jan. 13, 2011, and entitled "INTERACTIVE INPUT SYSTEM AND TOOL TRAY THEREFOR".

Imaging assemblies (not shown) are accommodated by the bezel **26**, with each imaging assembly being positioned adjacent a different corner of the bezel. Each of the imaging assemblies comprises an image sensor and associated lens assembly that provides the image sensor with a field of view sufficiently large as to encompass the entire interactive surface **24**. A digital signal processor (DSP) or other suitable processing device sends clock signals to the image sensor causing the image sensor to capture image frames at the desired frame rate. During image frame capture, the DSP also causes an infrared (IR) light source to illuminate and flood the region of interest over the interactive surface **24** with IR illumination. Thus, when no pointer exists within the field of view of the image sensor, the image sensor sees the illumination reflected by the retro-reflective bands on the bezel segments and captures image frames comprising a continuous bright band. When a pointer exists within the field of view of the image sensor, the pointer occludes IR illumination and appears as a dark region interrupting the bright band in captured image frames.

The imaging assemblies are oriented so that their fields of view overlap and look generally across the entire interactive surface **24**. In this manner, any pointer such as for example a user's finger, a cylinder or other suitable object, or a pen or eraser tool lifted from a receptacle of the tool tray **48**, that is brought into proximity of the interactive surface **24** appears in the fields of view of the imaging assemblies and thus, is captured in image frames acquired by multiple imaging assemblies. When the imaging assemblies acquire image frames in which a pointer exists, the imaging assemblies convey pointer data to the computing device **28**.

The general purpose computing device **28** in this embodiment is a personal computer or other suitable processing device comprising, for example, a processing unit, system memory (volatile and/or non-volatile memory), other non-removable or removable memory (e.g. a hard disk drive, RAM, ROM, EEPROM, CD-ROM, DVD, flash memory, etc.) and a system bus coupling the various computer components to the processing unit. The computing device **28** may also comprise networking capabilities using Ethernet, WiFi, and/or other suitable network format, to enable connection to shared or remote drives, one or more networked computers, or other networked devices. The computing device **28** processes pointer data received from the imaging assemblies and computes the location of any pointer proximate the interactive surface **24** using well known triangulation. The computed pointer location is then recorded as writing or drawing or used an input command to control execution of an application program as described above.

The interactive input system **20** also comprises a three-dimensional (3D) input device **52** that communicates with the computing device **28** via a USB cable **50**. Those of skill in the art will understand that alternative wired connections, such as for example VGA, DVI, HDMI and the like or suitable wireless connections to connect the 3D input device **52** to the computing device **28** may be employed. The 3D input device **52** comprises a camera **54** mounted to a base **58** via an articulated arm **56**. The camera **54** has a field of view that looks into a 3D input space **60**. The 3D input space **60** defines a volume within which a physical object or marker from a set of markers may be manipulated. FIG. **1**B better illustrates the 3D input space **60** together with a marker **62** from the set. For ease of illustration, only the camera **54** of the 3D input device **52** is shown. The 3D input space **60** in this embodiment takes the form of a pyramidal frustum. Thus, the 3D input space comprises six (6) boundary surfaces, i.e., front, back, left, right, top and bottom surfaces **70** to **80**. These boundary surfaces, except for the bottom surface **80**, may be used to define clipping planes, and used to detect a clipping planes gesture as described in International PCT Application Publication No. WO 2012/009789, filed on Jul. 19, 2011 and assigned to SMART Technologies ULC, the content of which is incorporated herein by reference in its entirety. The images captured by the camera **54** are processed by control circuitry (not shown) in the base **58** to adjust the brightness, clarity and/or resolution of the images and to convert the images into digital form, prior to being sent to the computing device **28**.

In this embodiment, each marker of the set is in the form of a planar card having a pattern printed or otherwise applied to at least one surface thereof, or a cube with at least one surface having a pattern printed or otherwise applied thereto. The pattern comprises a rectangular dark or black box having an arrangement of light or white blocks thereon. The arrangement of white blocks on the black box is unique to each marker. This allows each marker to be associated with different digital content **64** and/or with a different digital content manipulation. As shown in FIG. **1**A, the marker **62** is associated with digital content **64** in the form of an image of a stadium or arena that is presented on the interactive surface **24**.

When a marker is brought into the 3D input space **60** and is captured in an image acquired by the camera **54**, after the image has been preprocessed and converted into digital form by the control circuitry in the base **58**, the computing device **28** processes the image to recognize the pattern. Once recognized, the computing device **28** determines the digital content **64** associated with the recognized pattern. Thereafter, the computing device **28**, using a position mapping rule, combines the captured image, the digital content **64** associated with the recognized pattern on the marker and the graphical interface of the executing application program and outputs the resultant image data to the projector **38** for presentation on the interactive surface **24**. In this case, the digital content **64** is superimposed on the captured image and graphical interface. Thus, an image comprising both the real-world and digital content is displayed on the interactive surface **24**. Users of the interactive input system **20** may manipulate the marker **62**, e.g., by moving, rotating or tilting the marker **62** within the 3D input space **60**, to interact with and manipulate the digital content displayed on the interactive surface **24**. For example, a user may rotate the marker **62** to rotate the digital content **64** and view it from different vantage points as desired.

In some embodiments, some patterns on the marker **62** are recognized by the computing device **28** as digital tools, which may be used to facilitate the manipulation of digital content. Here, the digital content refers to 2D or 3D digital objects generated by the computing device **28** (in contrary to physical or real-world objects), and are represented by one or more graphic objects displayed on the interactive surface **24**. A digital tool is a digital object generated by the computing device **28** that may be used to manipulate other digital objects. However, a digital tool may also be considered as digital content when it is manipulated by other digital tools.

In order to recognize patterns on markers **62**, the computing device **28** maintains a pattern library comprising pattern reference images captured during interactive input system calibration, with each pattern reference image being captured with the pattern positioned at a known z coordinate (reference point) and orientation within the 3D input space **60**. In this embodiment, during pattern reference image capture, the patterns are positioned to lie in planes corresponding to the bottom plane **80** of the 3D input space **60**. In order to determine the z coordinate of a marker placed in the 3D input space **60**, the computing device **28** compares the size of the pattern in the pattern reference image to the size of the pattern in the image captured by the camera **54**. The ratio of the sizes allows the position of the marker along the z-axis of the 3D input space **60** to be determined. For example, if the ratio is equal to one (1), signifying that the size of the pattern in the pattern reference image and the size of the pattern in the image captured by the camera **54** are the same, the z coordinate of the marker is determined to coincide with the bottom plane **80**. The computing device **28** also calculates the marker's angle of rotation by comparing the direction of the pattern of the marker in the captured image to the pattern reference image, and calculates the angle of tilting based on the perspective distortion of the pattern in the captured image. In this embodiment, the top plane **78** is defined as an x-y plane at a location along the z-axis at which the image of the pattern captured by the camera **54** substantially occupies the entire field of view of the camera **54**.

Those skilled in the art will appreciate that other definitions of the 3D input space **60** and the reference point are also available. For example, in an alternative embodiment, the top plane **78** is defined at a position along z-axis at which the size of the marker that is parallel to the top and bottom planes in the captured image equals a pre-defined size. In another alternative embodiment, the reference point is defined at a known position along the z-axis at which the size of a marker seen by the camera **54** equals a predefined size. In this embodiment, the bottom plane **80** may be higher or lower than the reference point, depending on the interactive input system configuration.

FIG. **1**C shows an exemplary image **82** of the 3D input space **60** captured by the camera **54**. The borders **84** to **90** of the image **82** correspond to the planes **70** to **76**, respectively. During processing of the image **82**, the computing device **28** detects the coordinates of the marker **92** in the image **82**, and converts the coordinates to x-y coordinates of the 3D input space **60**. For example, if the marker **92** is near the border **88** in the image **82**, it is then determined that the marker **92** is proximate to the plane **74**. As described above, the marker's coordinate along the z-axis is calculated by comparing the size of the pattern **92** in the image **82** with the size of the corresponding pattern reference image in the library.

In this embodiment, the computing device **28** runs a host software application such as SMART Notebook™ offered by SMART Technologies ULC. As is known, during execution, the SMART Notebook™ application provides a graphical user interface comprising a canvas page or palette, that is output to the projector **38** and presented on the interactive surface **24**, and on which freeform or handwritten ink objects together with other computer generated objects can be input and manipulated via pointer interaction with the interactive surface **24**.

The SMART Notebook™ application provides a mixed reality (MR) mode in a page of a SMART Notebook™ file to display 3D digital tools and content, and allow users to manipulate them by using one or more markers brought into the 3D input space **60**. The computing device **28** automatically turns on the MR mode when a marker is detected in the 3D input space **60**, and turns off the MR mode when no marker is detected in the 3D input space. When the MR mode is turned on, the computing device **28** continuously tracks markers **62** in the 3D input space **60** to control the manipulation of digital content **64**. FIG. **2**A illustrates the process of manipulating digital content by tracking markers in the 3D input space **60**.

After the interactive input system **20** starts and the camera **54** is switched on (step **100**), the camera is set to a low-resolution mode with a slow frame rate so that the camera **54** captures a low-resolution image of the 3D input space **60** at regular intervals such as for example every three (3) seconds. When an image is captured, it is preprocessed and converted to a digital image by the control circuitry in the base **58** (step **102**). The digital image is then conveyed to the computing device **28** and the image is processed to detect whether a recognizable pattern is present in the image (step **104**).

If no recognizable pattern is present (the "No" branch of step **106**), the process reverts to step **102** and the next low resolution image is captured by the camera **54**. If it is determined that at least one pattern can be recognized (the "Yes" branch of step **106**), the computing device **28** turns on the MR mode (step **108**). At this step, the computing device **28** first checks to determine whether the Notebook™ application program is running. If yes, the computing device **28** turns on the MR mode in the current Notebook™ page; otherwise, the computing device **28** launches the Notebook™ application program, and turns on the MR mode in a new Notebook™ page.

When the MR mode is turned on, an MR window is overlaid on the Notebook™ page presented on the interactive surface **24**, displaying the image captured by the camera **54**. The graphic objects on the Notebook™ page are then brought into the MR window to allow users to manipulate the graphic objects using markers positioned within the 3D input space **60**. Then, the camera **54** is conditioned to a high-resolution mode and triggered so that the camera **54**, captures a high-resolution image of the 3D input space **60** (step **110**). The captured high-resolution image is preprocessed and converted to a digital image by the control circuitry in the base **58**. The digital image is then conveyed to the computing device **28** and the image is processed to detect whether a recognizable pattern is present in the image, and, if so, to recognize the pattern (step **112**).

If no pattern is recognized (the "No" branch of step **114**), the computing device **28** applies a transition effect (e.g., a fade-out effect) to the scene in the MR window (step **120**). The computing device **28** also starts a timer if not already started. At step **122**, the computing device **28** checks the timer to determine if a threshold period of time has elapsed. If not, the process reverts to step **110** and another high-resolution image of the 3D input space **60** is captured. If the threshold time period has elapsed, the computing device **28** then moves the digital content in the MR window to the current Notebook™ page and terminates the MR mode (step **124**). The process then ends (step **126**).

If, at step **112**, at least one pattern is recognized (the "Yes" branch of step **114**), the computing device **28** checks the timer to determine if it has been initiated. If so, the computing device **28** stops the timer and applies another transition effect (e.g., a fade-in effect) to the scene in the MR window (step **116**).

Then, the computing device **28** processes the MR scene in the MR window, and modifies the high-resolution image captured by the camera **54** before displaying it on the interactive surface **24** (step **118**). At this step, the computing device **28** compares the recognized pattern obtained from the captured image with the corresponding pattern reference image in the library to calculate the z coordinate of the marker in the 3D input space **60** and the rotation and tilting angles of the recognized pattern as described above. The x-y coordinates of the recognized pattern are directly calculated from the captured image. Historical data of the recognized pattern is also used to determine other parameters of the marker, such as for example, its velocity and acceleration of moving, rotating and tilting. The calculated parameters are then used to determine the interaction of the digital content in the image, which will be described herein. The image is then modified and displayed on the interactive surface **24**. The process then reverts to step **110** and another high-resolution image of the 3D input space **60** is captured by the camera **54**.

FIG. **2**B shows the steps performed during MR processing at step **118**. At step **142**, the computing device **28** determines the state of the marker and whether the state has changed from a previous state (step **144**). If the state of the marker has changed from a previous state, the computing device **28** sets a transition indicator associated with the marker to a value based on the type of state transition (step **146**), and the process proceeds to step **150**. If at step **144** it is determined that the state of the marker has not changed, the transition indicator is reset to "No transition", and the process proceeds to step **150**.

At step **150**, the computing device **28** determines the action or gesture of the marker based on the marker's type, state transition, value of the transition indicator and the parameters calculated above, and modifies the image presented on the interactive surface **24** so that the digital content is manipulated accordingly. For example, the movement of a content marker within the 3D input space **60** (i.e., a marker comprising a pattern representing digital content) causes the corresponding digital content to move accordingly. The rotation of a tool marker within the 3D input space **60** (i.e., a marker comprising a pattern representing a digital tool) may cause panning of the image presented on the interactive surface **24**.

At step **152**, the current state and the calculated parameters are saved as the marker's previous information and the process reverts to step **110**.

FIG. **3** shows the states and their transitions. In some embodiments, each marker transitions between four states, i.e., "Definitely not tracked" **162**, "Maybe not tracked" **164**, "Maybe tracked" **166** and "Definitely tracked" **168**. The state transition starts from the state "Definitely not tracked" **162**, signifying that the computing device **28** cannot recognize the marker. In this case, digital content associated with the marker that was previously presented on the interactive surface **24** is to be deleted. If the computing device **28** cannot recognize the marker, the marker stays in this state, and the transition indicator is reset to "No transition". However, if the computing device **28** recognizes the pattern of the marker, the marker then transitions to the state "Maybe tracked" **166**, signifying that the computing device **28** has recognized the marker and starts to track it. In this case, in some embodiments, the transition indicator is set to "Fade-in". Thus, when the computing device **28** performs actions or gestures (step **150** in FIG. **2**B), the digital content associated with the marker will gradually appear in the image presented on the interactive surface **24** with a fade-in effect.

In the state "Maybe tracked" **166**, if the pattern has been recognized for more than two (2) seconds, or another suitable threshold period of time, the marker then transitions to the state "Definitely tracked" **168**, signifying that the computing device **28** is affirmatively tracking the marker. The transition indicator is set to "Fade-in". If the computing device **28** loses tracking of the marker when the marker is in the state "Maybe tracked" **166**, the marker then transitions to the state "Maybe not tracked" **164**, signifying that the computing device **28** is losing track of the marker. The transition indicator is set to "Fade-out". Thus, when the computing device **28** performs actions or gestures (step **150** in FIG. **2**B), the digital content associated with the marker will gradually disappear in the image presented on the interactive surface **24** with a fade-out effect.

In the state "Definitely tracked" **168**, the marker stays in this state if the pattern is recognized, and the transition indicator is reset to "No transition". However, if the pattern cannot be recognized, the marker then transitions to the state "Maybe not tracked" **164**. The transition indicator is set to "Fade-out".

In the state "Maybe not tracked" **164**, if the marker has not been recognized for more than two (2) seconds, or another suitable threshold period of time, the marker then transitions to the state "Definitely not tracked" **162**, and the transition indicator is set to "Fade-out". However, if the marker is recognized when it is in the state "Maybe not tracked" **164**, the marker then transitions to the state "Maybe tracked" **166**, and the transition indicator is set to "Fade-in".

In this configuration, the digital content associated with the marker gradually appears when the marker is recognized by the computing device **28** and the digital content needs to be inserted into the image projected onto the interactive surface **24**. The digital content gradually disappears when the pattern cannot be recognized by the computing device **28** and the digital content needs to be deleted from the image projected onto the interactive surface **24**. Thus, users do not experience abrupt disappearing and appearing of digital content when the marker is brought out of or into the 3D input space **60** nor do users experience unwanted image flickering during temporary loss of marker tracking.

The transition and smoothing effects as well as some manipulation methods using gestures, such as for example, shaking, covering, stacking, swiping, etc., are described further in above-incorporated International PCT Application Publication No. WO 2012/009789 to Antonyuk et al.

FIGS. **4**A and **4**B illustrate an example of a SMART Notebook™ page transitioning from a non-mixed reality mode to a mixed reality (MR) mode. FIG. **4**A shows a SMART Notebook™ program window **180** that comprises two pages indicated by two page thumbnails **184** and **186**, respectively. Page thumbnail **184** is associated with page **182** currently displayed in the SMART Notebook™ program window **180**. Here and in the following examples, the page thumbnail associated with the current page that is displayed in the program window **180** comprises a thick border. Various pieces of digital content **188** (in this example, frogs and flowers) are displayed in the SMART Notebook™ page **182**.

In FIG. **4**A, the MR mode is turned off. The camera **54**, as described above, captures low-resolution images of the 3D input space **60** at regular intervals, which are processed by the computing device **28**. As shown in FIG. **4**B, when a marker **202** is brought into the 3D input space **60**, and the pattern carried by the marker is recognized by the computing device **28** during processing of an image captured by camera **54**, the MR mode is then turned on. A transparent MR window (not shown) is then overlaid on the SMART Notebook™ page **182** and the digital content **188** is brought into the MR window. In this example, the marker **202** is assumed not to be associated with digital content. Thus, the computing device **28** associates a 3D cursor **204** to the marker, and the 3D cursor **204** appears in the Notebook™ program window **180** with a transition effect, e.g., fade-in, proximate to the image of the marker **202**. Those skilled in the art will appreciate that if a marker having associated digital content is brought into the 3D input space **60**, and is recognized by the computing device **28** during processing of an image, the associated digital content will be shown in the SMART Notebook™ program window **180**.

In addition to the appearance of the 3D cursor **204**, a toolbar **206** also appears in the MR window. The toolbar **206** comprises various function tools for controlling the MR environment. For example, a close button **208** may be used to turn off the MR mode. Zoom buttons **210** may be used to control the zooming of the camera **54**. Focus buttons **212** may be used to manually or automatically adjust the focusing of the camera **54**. Brightness buttons **214** may be used to adjust the brightness or darkness of images captured by the camera **54**. An adjustable contrast bar **216** may be used to control the luminance of the camera **54**. In some embodiments, the user may also interact with control buttons on the base **58** to execute the same functions in the toolbar **206**. The camera icon **218** provides a visual indication signifying that the SMART Notebook™ page **182** is currently in the MR mode.

FIGS. **5**A to **5**C illustrate a rotation gesture for selecting digital content. In this embodiment, as shown in FIG. **5**A, a cube-shaped marker **222** is placed within the 3D input space **60** so that the marker **222** appears on the interactive surface **24** within a defined proximity of the 3D content **220** that the user wishes the marker to be associated with. It is assumed that cube-shaped marker **222** currently has no 3D digital content association. After the cube-shaped marker **222** has been rotated so that a different marker pattern is presented on the top face of the cube-shaped marker, following recognition of that pattern, the computing device **28** associates the marker pattern on the top face of the cube-shaped marker **222** with the 3D digital content **220**. A line segment **224** is introduced, connecting the top face of the cube-shaped marker and the 3D content **220**, indicating that the association has been made, as shown in FIG. **5**B. The user is now free to manipulate the views of the 3D content **220** through manipulation of the cube-shaped marker **222** within the 3D input space **60**. In FIG. **5**C, the user has rotated the cube-shaped marker **222** back to its original orientation, which results in the computing device **28** disassociating the 3D content **220** from the cube-shaped marker **222**.

FIGS. **6**A to **6**D illustrate an attraction technique for 3D content selection. As shown in FIG. **6**A, as the cube-shaped marker **222**, which is assumed to have no 3D content association, is moved within the 3D input space **60** so that its image displayed on the interactive surface **24** approaches the defined proximity of the 3D content **220** that the user wishes the marker to be associated with, the computing device **28** following processing of images captured by the camera **54**, animates the 3D content **220** so that the 3D digital content appears to move towards the cube-shaped marker **222**. This would appear to the user as if the 3D content **220** is attracted to the cube-shaped marker **222**. In FIG. **6**B, a segment **242** is shown connecting the cube-shaped marker **222** and the associated 3D content **220**, to signify visually to the user that the association has been made. In FIG. **6**C, the cube-shaped marker **222** is moved back and forth within the 3D input space **60** at a high rate in a shaking motion. This movement of the cube-shaped marker **222** within the 3D input space **60** is recognized by the computing device **28** as an input gesture, resulting in the computing device **28** disassociating the 3D content **220** from the cube-shaped marker **222**. As a result, the segment no longer connects the 3D content **220** to the cube-shaped marker **222**. In FIG. **6**D, the 3D content **220**, which has been disassociated from the cube-shaped marker **222**, is not manipulated when the cube-shaped marker **222** is moved within the 3D input space **60**.

FIGS. **7**A to **7**C illustrate a 3D content selection technique that makes use of a marker employing liquid crystal display (LCD) panels. In FIG. **7**A, the user is holding a cube-shaped marker **262** within the 3D input space **60** so that its image displayed on the interactive surface **24** appears within a defined proximity of the 3D content that the user **260** wishes the marker to be associated with. The LCD panels **266** on the outer surfaces of the cube-shaped marker **262** present various marker patterns. The marker patterns are assumed to have no 3D content association. Upon pushing button **264**, as shown in FIG. **7**B, the marker pattern presented by each LCD panel **266** changes to a different marker pattern. With this change, following processing of an image captured by the camera **54**, the computing device **28** associates the marker pattern on the top LCD panel **266** with the 3D content. As shown in FIG. **7**C, the button **264** has been released and the user **260** is able to manipulate the associated 3D content by moving the cube-shaped marker **262** within the 3D input space **60**.

FIGS. **8**A and **8**B show another method of content selection using a marker employing an LCD panel. FIG. **8**A shows a marker comprising an LCD panel **282** presenting a marker pattern **288**. The LCD panel **282** is attached to a handle **284**. A trigger button **286** is provided on the handle. It is assumed that the marker pattern **288** currently has no 3D content association. When the trigger button **286** is pushed, the marker pattern **288** presented by the LCD panel **282** changes to a new marker pattern **290**, as shown in FIG. **8**B. When this marker pattern **290** appears in the LCD panel **282** and the image of the LCD panel displayed on the interactive surface **24** is within a defined proximity of 3D content, following processing of an image captured by the camera **54**, the computing device **28** associates the marker pattern with the 3D content and the user is able to manipulate the views of the 3D content through manipulation of the LCD panel **282** within the 3D input space **60**. When the trigger button **286** is pushed again, the marker pattern **290** presented by the LCD panel will change to another marker pattern resulting in the computing device **28** disassociating the 3D content from the LCD panel **282**.

In yet another embodiment, the marker is in the form of an electronic device **295** having a display **294**. The electronic device **295** in this embodiment comprises a processing unit, system memory (volatile and/or non-volatile memory), other non-removable or removable memory (e.g. a hard disk drive, RAM, ROM, EEPROM, CD-ROM, DVD, flash memory, etc.) and a system bus coupling the various components to the processing unit. The electronic device **295** may also comprise a network interface which facilitates networking using Ethernet, WiFi, and/or other network format, to enable connection to shared or remote drives, one or more networked computers, or other networked devices. The electronic device **295** may also comprise one or more of ports for coupling external data or hard drives thereto. An exemplary port can enable the electronic device **295** to receive SIM cards, flash drives, or external hard drives.

As shown in FIG. **8**C, the electronic device **295** has a generally cuboid-shaped housing having one or more user input/output mechanisms thereon, such as buttons **296***a* to **296***c*, switches, track wheels, click wheels, keyboards, microphones and speakers. In addition, the electronic device **295** may comprise one or more cameras to capture visual images or video. In this embodiment, the display **294** of the electronic device **295** is a 3 inch, grayscale LCD display **294** with a 480×480 pixel resolution, which provides sufficient resolution so that displayed information captured by camera **54** can be readily processed by the computing device **28** and recognized. The display **294** is also dimensioned to allow the electronic device to be suitably designed for portability and manipulation in the 3D input space.

Images or video captured by the electronic device **295** may be stored in the memory within electronic device **295**, transmitted over a communications network to another electronic device, edited, or processed as desired. FIG. **8**D shows the electronic device **295** displaying an exemplary set of libraries each containing a plurality of electronic marker patterns. These libraries may be pre-selected on the computing device **28** and transferred to the electronic device **295** for storage via the network interface, or may be received from other sources, or composed on the electronic device **295**. Buttons **296***a* and **296***b* are used to navigate between libraries, while button **296***b* is used to select a desired library, and allow a user to select from the set of marker patterns associated with the selected library. When selecting between marker patterns, the electronic device **295** may display one or more marker patterns, or one or more representations of marker patterns. Generally, a representation of a marker pattern may be a scaled down image of the marker pattern, a text description of the digital content associated with the marker pattern, or an image of the digital content associated with the marker pattern, as shown in FIG. **8**E. In this case, buttons **296***a* and **296***b* are used to navigate between marker pattern representations, and button **296***b* is used to confirm a selection causing the marker pattern associated with the selected representation to be presented on display **294**.

Turning to FIG. **8**E once more, exemplary libraries **297***a*, **297***b* and **297***c* are shown and comprise marker patterns associated with digital content related geography, chemistry and biology, respectively. For example, a user may select library **297***a* containing geography related marker patterns and then choose a sub-category **298***b* related to 3D-earth content, which causes the display **294** to present a marker pattern associated with the 3D-earth content, as shown in FIG. **8**F. An image frame **82** captured by camera **54** including the electronic device **295** displaying the marker pattern is shown in FIG. **8**G. Although only one electronic device **295** is shown having one marker pattern within the field of view of the camera **54**, there may be other marker patterns, either displayed on another electronic device **295**, or on other media within the field of view of the camera **54**.

After the image **82** has been preprocessed and converted into digital form by the control circuitry in the base **58**, the computing device **28** processes the image **82** to recognize the marker pattern. Once recognized, the computing device **28** determines the digital content **64** associated with the recognized marker pattern. Alternatively, the electronic device **295** may transmit the identity of the displayed marker pattern to the computing device **28** which retrieves the associated digital content **64** from its libraries, thus bypassing the recognition step. Thereafter, the computing device **28**, using a position mapping rule, combines the captured image **82**, the digital content **64** associated with the recognized marker pattern and the graphical interface of the executing application program and outputs the resultant image data to the projector **38** for presentation on the interactive surface **24**.

In this case, the digital content **64**, such as a 3D earth object, is superimposed on the captured image and graphical interface. Thus, an image **64'**comprising both the real-world and digital content **64** is displayed on the interactive surface **24**. The electronic device **295** may be used to manipulate the displayed marker pattern e.g., by moving, rotating or tilting the electronic device **295** within the 3D input space **60**, to interact with the digital content **64** displayed on the interactive surface **24**. For example, a user may rotate the electronic device **295** to rotate the presented marker pattern and in turn rotate the digital content **64** and view it from different vantage points as desired.

The marker pattern may be a CyberCode matrix type barcode, although other types of matrix barcodes can be used, such as, a QR Code type matrix barcode **299***a*, as shown in **8**I. Other exemplary marker patterns may comprise a human readable marker, such as indicia resembling a black and white line drawing of a lion's head **299***b*, as shown in FIG. **8**J, or linear barcode markers **299***c*, as shown in FIG. **8**K. Alternatively, the marker pattern may comprise a visual depiction **300***a* of the digital content associated with the marker pattern, and a description **300***b* of the associated digital content, as shown in FIG. **8**L. Such information allows the user to easily select desired marker patterns and anticipate what will be shown in the augmented reality image **64'**. In another embodiment, images captured by camera of the electronic device **295** may be used as marker patterns.

In another exemplary embodiment, the housing of electronic device **295** comprises a set of marker patterns **301***d* to **301***i* applied to each face of the housing, as shown in FIG. **8**M. For example, marker pattern **301***d* is located on the front face of the electronic device **295** housing, marker pattern **301***e* is located on the opposing face of the housing (not shown), marker patterns **301***f* and **301***g* are located on two opposing side faces of the housing and marker patterns **301***h* and **301***i* are located on the other two opposing side faces of the housing. The marker patterns **301***d* to **301***i* allow the position and orientation of the electronic device **295** to be determined and tracked, while the marker pattern presented on the display **294** is analyzed to determine the associated digital content. Once the computing device **28** has determined the associated digital content, the computing device **28** then uses the location and orientation of marker patterns **301***d* to **301***i* to manipulate the digital content while a user selectively positions the electronic device **295** within the 3D input space. Accordingly, the digital content persists even when the marker pattern presented on the display can not be seen by the camera **54**, especially, during rotating actions, tilting actions or occlusions. Alternatively, marker patterns **301***d* to **301***i* may be incorporated into the corners of the housing of electronic device **295** and take the form of contrasting black and white lines, linear or matrix bar codes, or illuminated areas from illuminations sources such as IR LEDs.

FIGS. **9**A to **9**C illustrate 3D content selection utilizing a dwelling technique. FIG. **9**A shows a mixed reality canvas page **182** with selectable 3D content **302** and **304** presented thereon (in this example a frog and a stadium). A marker **190** that is assumed to have no associated 3D content is positioned within the 3D input space **60**. As a result, following processing of images captured by the camera **54**, the computing device **28** generates a 3D cursor **192** that appears proximate to the image of the marker within the canvas page **182**. As shown in FIG. **9**B, as the marker **190** is moved within the 3D input space to position the 3D cursor **192** within the defined proximity of the 3D content **304** that the user wishes the cursor to be associated with, the computing device **28** animates the 3D content **304** and visually scales the 3D content **304** down in size to provide a feeling of attraction to the 3D cursor **192**. The 3D content **304** appears on top of the 3D cursor **192**. The timer as described previously is started and a timing indication **306** is shown over the 3D content **304**. The user is required to maintain the marker **190** within the defined proximity of the 3D content for a time period longer than the threshold time period (determined by the timer and indicated by the timing indication **306**) in order to associate the 3D content **304** to the marker **190**. If the 3D cursor **192** is moved beyond the defined proximity before the threshold time period has elapsed, the 3D content **304** will not become associated with the marker **190**. However, as shown in FIG. **9**C, if the threshold time period has elapsed while the marker **190** remains within the defined proximity of the 3D content **304**, then the computing device **28** associates the 3D content **304** to the marker **190**, and removes the 3D cursor **192** since the 3D content has now been associated to the marker **190**. The 3D content **304** is then returned to its original size and the user may manipulate the views of the selected 3D content **304** as desired by moving the marker **190** within the 3D input space **60**.

The above process is summarized by the following pseudo code:

```
L1: CubePosition3D = 3D position of the tracked marker that is not associated with digital content;
L2: CubePosition2D = Calculating projection of CubePosition3D onto the 2D Notebook ™ page;
L3: For each digital content on the Notebook ™ page,
    L4: ContentPosition2D = Calculating projection of 3D content position onto the 2D Notebook ™ page;
    L5: Distance = distance between ContentPosition2D and CubePosition2D;
    L6: If Distance < 50 mm
    L7: Scale content by Distance / 50;
    L8: If Distance < 20 mm
        L9: Start the dwell timer to select content if timer has not already started (note: 2 seconds dwell is required)
        L10: If time elapsed < 2 seconds
            L11: Render arc centered around ContentPosition2D with angle (time elapsed) / (2 seconds) * 2Pi
        L12: Else
            L13: Select content and apply animated transition to position it on top of the marker
        L14: End If
    L15: Else
        L16: Stop and reset dwell timer; reset the content to its original size;
    L17: End If
L18: End For
```

In the above pseudo code, the distance between the 3D cursor and the 3D content to determine if the 3D cursor is within the defined proximity of the 3D content is measured in millimeters. Those skilled in the art will appreciate that, in alternative embodiments, pixels or other suitable units may be used to measure the distance. Moreover, instead of using two seconds as the threshold time period, in some alternative embodiments, a different threshold time period may be used.

Although not shown, the user may cover the marker to disassociate the 3D content with the marker. The process of disassociating the 3D content with the marker after detection of the covering gesture may be summarized by the following pseudo code:

```
L1: If cover gesture detected
    L2: Start disassociation timer if it has not already started (note: 2 seconds deselect is required)
    L3: If time elapsed < 2
        L4: Render arc centered around ContentPosition2D with angle (1 − (time elapsed) / (2 seconds)) * 2Pi
    L5: Else
        L6: Disassociate content with the marker and apply animated transition to position it back on the Notebook ™ page
    L7: End If
L8: End If
```

Those skilled in the art will appreciate that instead of using two seconds as the threshold time period, in some alternative embodiments, a different threshold time period may be used.

In some embodiments, a cube with each surface having a different pattern may be used to select from a set of predefined digital content. As shown in FIG. **10**A, a selection tool in the form of a cube **402** with each surface of the cube having a different pattern thereon, is positioned within the 3D input space **60** and with the surface **404** facing the camera **54**. The user is then assumed to apply a covering gesture (not shown) or another appropriate gesture to the cube **402** that is recognized by the computing device **28** through processing of images captured by the camera **54**. In response, the computing device **28** displays an indicator **408** that starts to grow with a predefined speed to indicate the time that the covering gesture is maintained. When a predefined threshold time period has passed (indicated by the indicator growing to a full circle), the computing device **28** presents a menu **410** comprising six (6) digital contents **412** to **422** around the image of the cube **402** with an animation effect (e.g., fade-in) as shown in FIG. **10**B. The menu **410** is arranged in such a way that the position of each digital content indicates the surface of the cube **402** to which it may be associated. For example, the digital content **412** overlaps with the image of the cube **402** indicating that it may be associated with the top surface **404**. Digital content **414** to **420** are shown along the four sides of the image of the cube **402** indicating that they may be associated with the corresponding side surface of the cube **402**. The digital content **422** is shown with a line linking to the cube **402** indicating that it may be associated with the bottom surface of the cube **402**.

The user may rotate the cube **402** within the 3D input space **60** to present another surface to the camera **54** to select digital content. For example, if the user rotates the cube **402** by 90 degrees along the direction indicated by the arrow **426**, the digital content **414** is then selected. As illustrated in FIG. **10**C, an indicator **428** is shown and starts to grow with a predefined speed. The selection is confirmed when the indicator **428** grows to a full circle.

Various tools may be associated with markers for manipulating digital content. FIGS. **11**A to **11**C illustrate a "black hole" tool for erasing digital content displayed on the interactive surface **24**. In FIG. **11**A, when the marker associated with the "black hole" tool **440** is positioned within the 3D input space **60**, the associated "black hole" tool appears in the displayed image. When the marker is manipulated in the 3D input space **60** to bring the "black hole" tool into the proximity of the digital content **442** with a distance less than a predefined threshold, after a threshold period of time has passed with the "black hole" tool **440** proximate the digital content, the computing device **28** recognizes an erase command. In response, the computing device **28** starts to shrink and fade-out the digital content **442**, as shown in FIG. **11**B, and, as shown in FIG. **11**C, eventually erases the digital content from the image displayed on the interactive surface **24**.

FIG. **12**A shows a magnifying glass tool **460** having a magnifying window **462**. When the marker associated with the magnifying glass tool **460** is positioned within the 3D input space **60**, the associated magnifying glass tool **460** appears in the displayed image. When the marker is manipulated in the 3D input space **60** to bring the magnifying glass tool **460** into proximity of the digital content **464** and the magnifying window **462** is substantially overlapped with a portion of the digital content **464**, the computing device **28** in response presents a magnified image of the digital content **464** in the magnifying window **462**.

FIG. **12**B shows a layer-view tool **480** having a layer-view window **482**. The layer-view tool **480** is for use with digital content **484** that comprises multiple layered images. In this example, the digital content **484** comprises a second image **488** covered by a first image **486** so that the second image **488** is not displayed. When the marker associated with the layer-view tool **480** is positioned within the 3D input space **60** and manipulated such that the window **482** of the layer-view tool substantially overlaps with a portion of the digital content **484**, the portion of the second image **488** overlapped with the layer-view window **482** is displayed by the computing device **28**. If the digital content **484** comprises more than two layers, the user may apply a gesture, e.g., shaking gesture, to the layer-view tool **480** to see other layers. In some alternative embodiments, additional information of the digital content **484** may also be shown by using the layer-view tool **480**.

In some embodiments, multiple markers may be used to manipulate the same digital content. FIG. **13** illustrates the interaction of digital content **500**, such as for example a 3D model of a city, by using two markers **506** and **508**. As will be described later, the marker **506** determines the viewable portion of the digital content **500**, and the marker **508** representing a virtual camera, determines the detailed view of the digital content **500**.

As shown in FIG. **13**, the digital content **500** is zoomed to a user to a specified level so that only a detailed view of a portion of the digital content **500** is displayed in a detailed-view window **502** (e.g., a Notebook™ page or the entire interactive surface **24**). A preview window **504** is overlapped with the detailed-view window **502** showing a full view of the digital content **500**. A rectangular box **510** inside the preview window **504** indicates the viewable portion of the digital content **500**. The digital content in the detailed-view window and the preview window may be different. For example, the preview window may show a 2D map of the content **500**, while the detailed-view window may show a 3D view of the content **500**.

The two markers **506** and **508** are used to interact with the digital content **500** through manipulations of the markers within the 3D input space **60**. The x-y coordinates of the marker **506** determine the position of the rectangular box **510** in the preview window **504**, and thus determine the viewable portion of the digital content **500**. The marker **508** representing a virtual camera is shaped in such a way that it comprises a recognizable direction indicating the direction of the virtual camera view. The computing device **28** determines the direction of the marker **508** and the distance between the markers **506** and **608**, which are then used to calculate the position and viewing direction of the virtual camera with respect to the digital content **500**. An image **512** of the virtual camera is displayed in the preview window **504** at the calculated position, which indicates the direction the virtual camera is viewing. The image of the digital content **500** displayed in the detailed-view window **502** is also adjusted according to the position and the viewing direction of the virtual camera.

By moving the virtual camera marker **508** within the 3D input space **60**, the user can freely move around within the viewable portion of the digital content **500** and view perspectives thereof. The user may also move the marker **506** within the 3D input space **60** to select another portion of the digital content for viewing via the virtual camera.

The use of physical markers in the 3D input space **60** provides users great flexibility to manipulate digital content. As described above, the computing device **28** detects the movement, rotation and tilting of a marker and then determines the interaction to be applied to the associated digital content. In some embodiments, the interaction applied may change the position and/or angle of digital content, or replace digital content with alternative digital content. In some other embodiments, the action of a marker may change some parameters of the associated digital content.

For example, in some embodiments, the computing device **28** may interpret the rotation of a cube-shaped marker with respect to its z-axis (see FIG. **14**A) as a command changing the length of the associated digital content, and may interpret the rotation of the marker with respect to its x-axis as a command changing the color mix of the digital content. Shown in FIG. **14**B, digital content **522** is associated with a marker in the form of a cube **520** (the marker patterns on the cube are not shown). When the user rotates the cube about its z-axis as indicated by the arrow **524** within the 3D input space **60**, as shown in FIG. **14**C, the length of the digital content **522** is increased. Rotating the cube **624** in the opposite direction decreases the length of the digital content.

FIG. **14**C shows digital content **532** associated with a cube **530** (the marker patterns on the cube are again not shown) that is filled with two colors **534** and **536**, where the color **536** fills in more area than the color **534**. The user rotates the cube about its x-axis as indicated by the arrow **538** within the 3D input space **60**. As a result shown in FIG. **14**E, the area filled by the color **534** is increased and the area filled by the color **536** is decreased. Rotating the cube **530** in the opposite direction decreases the area filled by the cube **534** and increases the area filled by colour **536**

FIG. **15**A shows digital content **560** in the form of an e-book that is associated with two cubes **562** and **564**, where the association is visually indicated by the links **566** and **568**, respectively. The user may rotate the markers **562** and **564** to the left and right as indicated by the arrows **570** and **572**, respectively within the 3D input space **60** to manipulate the digital content **560** (i.e., to open the e-book **560** and leaf through its pages).

FIG. **16**A shows digital content **600** in the form of a cylinder that is associated with two cubes **602** and **604**. The user may rotate the cubes oppositely with respect to the z-axis and, at the same time, move the cubes **602** and **604** towards each other to the new positions **610** and **612**, as indicated by the arrows **606** and **608**, respectively, within the 3D input space **60** to manipulate the digital content **600**. As shown in FIG. **16**B, in response to cube movement within the 3D input space **60**, the shape of the digital content **600** is changed, i.e., twisted towards the new positions **610** and **612**.

FIG. **17**A shows digital content **640** in the form of a stadium that is associated with two cubes **642** and **644**. The user may move the cubes **642** and **644** away from each other within the 3D input space **60** to manipulate the digital content **640**. As shown in FIG. **16**B, in response to cube movement within the 3D input space **60**, the digital content **640** is enlarged.

While manipulating the digital content by using associated markers, rules may be applied to reject invalid operations based on the characteristics of the digital content. For example, in FIG. **18**A, where digital content **660** in the form of a stadium is associated with two cubes **662** and **664**, the characteristics of the stadium **660** do not allow it to be twisted. Therefore, when the user moves the cubes **662** and **664** away from each other and, at the same time, rotates them oppositely with respect to the z-axis, within the 3D input space **60**, as indicated by the arrows **666** and **668**, respectively, the rotations of the markers are ignored. As shown in FIG. **18**B, the stadium **640** is thus enlarged without twisting.

FIG. **19**A shows another example where digital content **700** in the form of a globe is associated with a cube **702**. According to the characteristics of the globe **700**, only the rotation of the cube with respect to z-axis is accepted, which results in the globe rotating along its longitude. When the user rotates the cube imperfectly with the rotation axis not parallel to the z-axis, e.g., as indicated by the arrow **704**, the computing device **28** detects the rotation of the cube **702**, and projects the rotation to the x-y plane to obtain the rotation vector with respect to the z-axis. Then, the computing device **28** applies the projected rotation vector to the digital content **700**. As shown in FIG. **19**B, although the cube **702** is rotated and tilted within the 3D input space **60**, the digital content is rotated without tilting.

In some embodiments, the computing device **28** adapts the image of the digital content to the motion of the marker associated therewith. The digital content may comprise a set of predefined images or may be associated with a model such that the image of the digital content may be changed according to the rules of the model. When the marker associated with such digital content is manipulated in the 3D input space **60**, the computing device **28** detects the motion of the marker and calculates parameters such as for example the velocity, acceleration, rotating/tilting angles, path, etc., as described above, and updates the image of the digital content to follow the motion of the marker in real-time. When updating the image of the digital content, the computing device **28** also modifies the image of the digital content by replacing the current image with another image from the set of images, or by replacing the current image with an image generated according to the rules of the associated model. The modification of the image of the digital content is based on the motion of the marker.

FIG. **20** shows an example of modifying the image of the digital content based the motion of the marker. A marker in the form of a cube placed at position **742**A is associated with 3D digital content **740**A in the form of a snake. The user moves the cube from the position **742**A to another place **740**B in the 3D input space **60**. The computing device **28** detects the movement of the cube, and calculates the path **744**A between the two positions **742**A and **742**B. Then, the computing device **28** moves the snake **740**A to a place corresponding to the marker's current position **740**B, and modifies the image of the snake **740**A to the image **740**B such that the shape of the snake matches the path **744**A. When the user moves the cube to position **742**C, the computing device **28** again calculates the path **744**B, and then moves the snake to a position corresponding to the marker's position **742**C and modifies the image of the snake to image **740**C such that the image **740**C matches the path **744**B.

In FIG. **21**, 3D digital content **780**A in the form of a horse is associated with a cube at the position **782**A. Because the cube is stationary, the image of the digital content shows the image of a standing horse. When the user moves the cube to a second position **782**B within the 3D input space **60**, the computing device **28** detects the movement of the cube, and calculates parameters of the marker, including the velocity of the marker and the path **784**A. Then, the computing device **28** moves the horse to the position corresponding to the marker's current position **782**B, and, because the velocity of the marker is not zero, updates the image of the digital content to a running horse **780**B.

The user then moves the cube to a third position **782**C which is higher than the previous position **782**B within the 3D input space **60**, the computing device **28** detects the movement of the cube, and calculates parameters of the marker, including the velocity of the marker and the path **784**B. The velocity, which is a vector in 3D space, indicates that the cube is moving upward with a high speed. Therefore, the computing device **28** moves the horse to the position corresponding to the marker's current position **782**C, and updates the image of the digital content to a horse with a pose of jumping up **780**C.

The user then moves the cube to a fourth position **782**D which is lower than the previous position **782**C within the 3D input space **60**. The computing device **28** detects the movement of the cube, and calculates parameters of the marker, including the velocity of the marker and the path **784**C. The velocity indicates that the cube is moving downward with a high speed. Therefore, the computing device **28** moves the horse to the position corresponding to the marker's current position **782**D, and updates the image of the digital content to a horse with a pose of jumping down **780**D.

In some embodiments, the interactive input system **20** may be used in education, e.g., teaching physics or asking students to answer questions. FIGS. **22**A to **22**C show digital content **806** in the form of a spring coil associated with two markers **802** and **804**. In FIG. **22**A, the user moves the markers **802** and **804** towards each other within the 3D input space **60**, as indicated by the arrows **808** and **810**, respectively. In response, the digital content **806** is updated by the computing device **28** to show an image of a compressed spring coil, together with two arrows **812** and **814** at each end of the spring coil **806**, respectively, to indicate the force generated in the compressed spring coil **806**.

In FIG. **22**B, the user manipulates the markers **802** and **804** to bend the spring coil **806**, using the method described above. Then, the computing device **28** updates the image of the digital content **806** to show a bent spring coil, and shows four arrows **820** to **826** to indicate the force generated in the spring coil **806**.

In FIG. **22**C, the user moves the marker **802**, as the arrow **840** indicates, to twist the spring coil **806**. Then, the computing device **28** updates the image of the digital content **806** to show a twisted spring coil, and shows six arrows **842** to **852** to indicate the force generated in the spring coil **806**.

FIG. **23** shows two cubes **862** and **864**. Each surface of each cube comprises a marker pattern (not shown), and is associated with a word, e.g., the words **866** to **872** as shown in FIG. **23**. A number of words **860** are also displayed on the interactive surface **24**. The user is required to rotate the cubes to certain positions within the 3D input space **60** such that the words associated with the surfaces of the cubes facing the camera **54** match the words **866** to **872** in the prescribed order. The computing device **28** in this case ignores translations of the cubes **862** and **842**, but processes rotations thereof. After a threshold time period has passed with the cubes positioned as described above, the computing device **28** determines whether the user's answer is correct or not. An audio or video indication of correctness is then provided.

The interactive input system allows the user to switch to another SMART Notebook™ page while the MR mode is turned on. FIGS. **24**A and **24**B show a SMART Notebook™ program window **900** that comprises two pages **902** and **920** associated with page thumbnails **910** and **912**, respectively. In FIG. **24**A, page **902** is the current page, which is indicated by the thick border of page thumbnail **910**. The current page **902** is in MR mode. The MR window, in the form of a transparent window, is overlaid on a SMART Notebook™ page that comprises two digital contents **904** and **906**. The digital content **904** is not associated with a marker, and the digital content **906** is selected by the marker **908**.

The user may select the page thumbnail **912** to switch to page **920**. As shown in FIG. **24**B, the content of the page **920** is then shown on the interactive surface **24**. The page thumbnail **910** is changed to a thin border, and the page thumbnail **912** is changed to a thick border. After page **920** becomes the current page, it is automatically conditioned to the MR mode, and the MR window is overlaid thereon. The digital content in page **920**, e.g., the content **922**, are brought into the MR window. The digital content not associated with any marker when page **902** was the current page are left therein after the current page is switched to page **920**. The digital content associated with or selected by markers when page **902** was the current page are moved to page **920** with the MR window. For example, while the digital content **904** is left in page **902**, the digital content **906**, which is selected by the marker **908**, is moved to page **920** with the MR window.

Those skilled in the art will appreciate that various alternative embodiments are readily available. Although the interactive board **22** is described as being mounted on a vertical support surface, those of skill in the art will appreciate that the interactive board may be supported on a stand or other suitable framework or suspended from overhead structure. Of course interactive boards employing other machine vision configurations, analog resistive, electromagnet, capacitive, acoustic or other technologies to register pointer input may be employed. Also, rather than taking a vertical configuration, the interactive board may be in the form of a touch table comprising a horizontal oriented interactive surface.

In some alternative embodiments, the interactive input system may comprise no 2D input device. In this case, a projector **38** may be used with a display surface (e.g., a projection screen) to display images output by the computing device **28**.

Although in above embodiments, fade-in/fade-out are used as the transition effects, those of skill in the art will appreciate that other transition effects may be employed. For example, instead of using a fade-in effect, a zoom-in effect may be used, with which digital content is brought onto the display with an effect of scaling up from a tiny size to its full size. Instead of using a fade-out effect, a zoom-out effect may be used, with which digital content is removed from the display by scaling it from its current size to a tiny size and then disappear.

Although in above embodiments, the 3D input space is defined as a pyramidal frustum shape, those of skill in the art will appreciate that the 3D input space may take other 3D shapes such as for example, a cube, a cylinder or a sphere. In this case, the planes are also properly defined according to the shape of the 3D interactive space, and may not necessarily be a flat plane.

Those skilled in the art will appreciate that, in some alternative embodiments, while a pattern is recognized and the associated digital content is inserted into the image presented on the interactive surface, when a pattern is recognized the associated digital content may be deleted from the image presented on the interactive surface.

Those of skill in the art will appreciate that the above description of the toolbar for controlling the MR environment is for illustrative purpose only. Other functions are also available, and the toolbar may comprise more or less functions than the above description. In some alternative embodiments, the camera icon **206** may take the form of a button that allows the user to switch between the MR mode and a normal camera mode in which images captured by the camera **54** are shown in the Notebook™ program window without entering the MR mode. In other alternative embodiments, the icon **206** changes between a camera icon and a mixed reality marker pattern icon, to indicate to the user the current camera mode (the normal camera mode or the MR mode).

In some alternative embodiments, a line segment may or may not be used to connect the 3D content to the marker, to show the user that the association has been created.

In some alternative embodiments, the user can be interacting with any application running on the computing device **28** before entering into the mixed reality mode. Once the marker pattern has been recognized by the computing device **28**, a transition to the mixed reality mode is activated and displayed to the user. An automatic URL may be activated upon recognition of a mixed reality marker.

In some alternative embodiments, the cube-shaped marker employing LCD panels can have multiple buttons for additional functionality. Additional functionality can include for example an on/off, select content, disassociate content, etc. function. Those of skill in the art will also appreciate that not all LCD panels of the cube-shaped marker have to be active when the button is pushed. The top facing LCD panel of the cube-shaped marker can be active while the other LCD panels remain markerless.

In some alternative embodiments, the LCD panels will begin in an "off" state. By moving the LCD panels within the defined proximity of 3D content, and triggering the button to turn on the LCD panels, the 3D content will become associated with the marker pattern displayed on the top LCD panel. When the LCD panel is turned "off", the marker will become disassociated with the 3D content.

Although in above description, a menu comprising a set of predefined digital content may be opened by the manipulation of a physical object, those skilled in the art will appreciate that other types of menus may also be opened by the manipulation of a physical object. For example, a menu comprising a set of text-based menu items may be opened, and a menu item may be selected by the manipulation of a physical object.

Although embodiments have been described above with reference to the accompanying drawings, those of skill in the art will appreciate that variations and modifications may be made without departing from the scope thereof as defined by the appended claims.

What is claimed is:

1. An interactive input system comprising:

computing structure; and

an input device detecting at least one electronic device displaying a recognizable pattern within a three-dimensional (3D) input space and providing output to said computing structure, wherein said computing structure processes the output of the input device to:

recognize the pattern displayed by the at least one electronic device in the 3D input space;

detect the state of the at least one electronic device; and

modify image data representing at least digital content associated with the displayed pattern and the displayed pattern by applying a transition to the digital content associated with the displayed pattern based on the detected state of the at least one electronic device; and

a display coupled to said computing structure, the display presenting an image based on said image data,

wherein when the detected state of the at least one electronic device signifies that a new recognizable pattern is visible thereon and the new recognizable pattern is maintained in the 3D input space within a threshold distance of a location corresponding to digital content in the image presented on the display for a threshold time period, the image data is further modified to associate the digital content with the new recognizable pattern, the associated digital content appearing in the image presented on the display using a visual effect.

2. The interactive input system of claim **1** wherein said input device is a camera device capturing images of said 3D input space.

3. The interactive input system of claim **1** wherein said recognizable pattern is associated with at least one secondary recognizable pattern located at predetermined positions on said at least one electronic device.

4. The interactive input system of claim **3** wherein said at least one electronic device has a generally cuboid-shape and comprises at least one secondary recognizable pattern on each face of the electronic device.

5. The interactive input system of claim **4** wherein the at least one secondary recognizable pattern is located adjacent each corner of the electronic device.

6. The interactive input system of claim **5** wherein the at least one electronic device comprises processing structure, memory for storing instructions executable by the processing structure, and data representing at least one recognizable pattern, and a display for presenting at least one recognizable pattern.

7. The interactive input system of claim 6 wherein said data represents a library of recognizable patterns.

8. The interactive input system of claim 7 wherein said data is downloadable by the processing structure of said electronic device from a remote source.

9. The interactive input system of claim 8 wherein said at least one electronic device is an ebook.

10. The interactive input system of claim 1 wherein said at least one electronic device has a plurality of display panels for displaying recognizable patterns.

11. The interactive input system of claim 10 wherein said at least one electronic device is a cube comprising display panels on faces thereof.

12. The interactive input system of claim 11 wherein said display panels are liquid crystal display panels.

13. The interactive input system of claim 1 wherein said at least one electronic device comprises a liquid crystal display panel.

14. The interactive input system of claim 1 wherein said display is an interactive surface.

15. The interactive input system of claim 1 wherein the computing structure processes the output of the input device to detect at least one of orientation, position and movement of the at least one electronic device in the 3D input space.

16. The interactive input system of claim 1 wherein when the detected state of the at least one electronic device signifies removal of a previously recognizable pattern thereon, the image data is modified to remove associated digital content therefrom, the associated digital content disappearing from the image using a different visual effect.

17. The interactive input system of claim 1 wherein the visual effect is a fade-in visual effect or a scale-up visual effect.

18. The interactive input system of claim 16 wherein the different visual effect is a fade-out visual effect or a scale-down visual effect.

19. The interactive input system of claim 1 wherein the computing structure further processes the output of the input device to detect gestures made using said at least one electronic device.

20. The interactive input system of claim 19 wherein said computing structure manipulates digital content associated with the at least one electronic device in response to detected gestures.

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